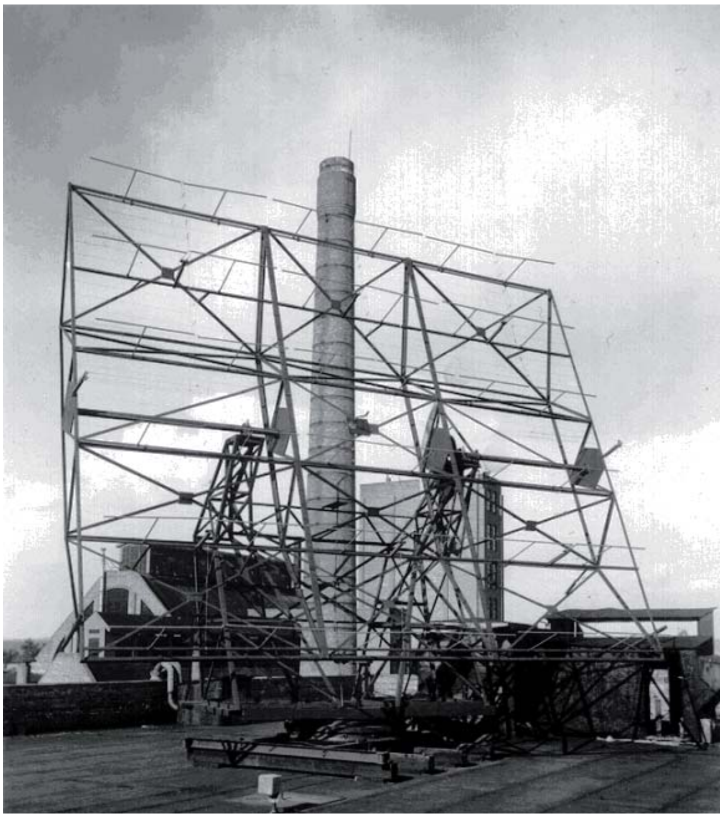
Radio Science Bulletin

ISSN 1024-4530

INTERNATIONAL
UNION OF
RADIO SCIENCE

UNION
RADIO-SCIENTIFIQUE
INTERNATIONALE

Special Section on Some Less-Well-Known Contributions to the Development of Radar: From its Early Conception Until Just after the Second World War



No 358
September 2016

URSI, c/o Ghent University (INTEC)
St.-Pietersnieuwstraat 41, B-9000 Gent (Belgium)

Contents

Cover: The planar phased array antenna of the Hungarian radar used to measure the distance between the moon and the Earth. See the paper by István Balajti and Ferenc Hajdú in the special section on "Some Less-Well-Known Contributions to the Development of Radar: From its Early Conception Until Just After the Second World War" (figure courtesy of Pál Szabó; see reference [5] in the paper).

The International Union of Radio Science (URSI) is a foundation Union (1919) of the International Council of Scientific Unions as direct and immediate successor of the Commission Internationale de Télégraphie Sans Fil which dates from 1914.

Radio Science Bulletin Staff

Editor

W. R. Stone
Stoneware Limited
840 Armada Terrace
San Diego, CA 92106, USA
Tel: +1-619 222 1915, Fax: +1-619 222 1606
E-mail: r.stone@ieee.org

Editor-in-Chief

P. Lagasse
URSI Secretariat
Ghent University - INTEC
Technologiepark - Zwijnaarde 15
B-9052 Gent, BELGIUM
Tel: +32 9-264 33 20, Fax: +32 9-264 42 88
E-mail: lagasse@intec.ugent.be

Production Editors

I. Lievens
I. Heleu
URSI Secretariat / Ghent University - INTEC
Technologiepark - Zwijnaarde 15
B-9052 Gent, BELGIUM
Tel: +32 9-264.33.20, Fax: +32 9-264.42.88
E-mail: ingeursi@intec.ugent.be, info@ursi.org

Senior Associate Editors

A. Pellinen-Wannberg
Department of Physics
Umea University
BOX 812
SE-90187 Umea, SWEDEN
Tel: +46 90 786 74 92, Fax: +46 90 786 66 76
E-mail: asta.pellinen-wannberg@umu.se

O. Santolik
Institute of Atmospheric Physics
Academy of Sciences of the Czech Republic
Bocni II
1401, 141 31 Prague 4, CZECH REPUBLIC
Tel: +420 267 103 083, Fax +420 272 762 528
E-mail os@ufa.cas.cz, santolik@gmail.com

Associate Editors, Commissions

Commission A

P. Tavella
INRIM
Strada delle Cacce 91
10135 Torino, ITALY
Tel: +39 011 3919235, Fax: +39 011 3919259
E-mail: tavella@inrim.it

P. M. Duarte Cruz
Instituto de Telecomunicações
Campus Universitário de Santiago
P-3810-193 Aveiro, PORTUGAL
Tel: +351 234377900
E-mail: pcruz@av.it.pt

Commission B

K. Kobayashi
Dept. of Electrical, and Communication Engineering
Chuo University
1-13-27 Kasuga, Bunkyo-ku
Tokyo, 112-8551, JAPAN
Tel: +81 3 3817 1846/69, Fax: +81 3 3817 1847
E-mail: kazuya@tamacc.chuo-u.ac.jp

L. Li
School of EECS
Peking University
Room 2843N, Science Building#2
Beijing 100871, CHINA CIE
Tel: +86-10-62754409-2 , Fax: +86-10-62754409
E-mail: lianlin.li@pku.edu.cn

Commission C

S. E. El-Khamy
Dept. of Electrical Engineering
Alexandria University - Faculty of Engineering
Abou-Keer Street
Alexandria 21544, EGYPT
Tel: +2010-1497360, Fax: +203 5971853
E-mail: elkhamy@ieee.org, said.elkhamy@gmail.com

A. I. Zaghloul
Ece, Virginia Tech
7054 Haycock Rd
22043 Falls Church, USA
Tel: +1-703-538-8435, Fax: +1-703-538-8450
E-mail: amirz@vt.edu

Commission D

G. Gradoni
School of Mathematical Sciences
University of Nottingham
University Park
Nottingham NG7 2RD, UNITED KINGDOM
Tel: +44(0)7745368300, Fax: +44(0)1159514951
E-mail: gabriele.gradoni@gmail.com, gabriele.gradoni@nottingham.ac.uk

Commission E

F. Gronwald
Hamburg University of Technology
Harburger Schloss Strasse 20
21079 Hamburg, GERMANY
Tel: +49-40-42878-2177
E-mail: gronwald@tuhh.de

G. Gradoni
School of Mathematical Sciences
University of Nottingham
University Park
Nottingham NG7 2RD, UNITED KINGDOM
Tel: +44(0)7745368300, Fax: +44(0)1159514951
E-mail: gabriele.gradoni@gmail.com, gabriele.gradoni@nottingham.ac.uk

Commission F

V. Chandrasekar
Engineering B117
Colorado State University
Fort Collins, Colorado 80523 , USA
Tel: +1 970 491 7981, Fax: +1 970 491 2249
E-mail: chandra@engr.colostate.edu, chandra.ve@gmail.com

M. Kurum
Department of Electrical and Computer Engineering
The George Washington University
800 22nd Street
NW, Washington, DC 20052, USA
Tel: +1 202 994 6080
E-mail: mkurum@gmail.com

Commission G

P. Doherty
Institute for Scientific Research
Boston College
140 Commonwealth Avenue
Chestnut Hill, MA 02467, USA
Tel: +1 617 552 8767, Fax: +1 617 552 2818
E-mail: Patricia.Doherty@bc.edu

Commission H

J. Lichtenberger
Eötvös University
Pazmany Peter Setany 1/a
H-1111 Budeapest
HUNGARY
Tel: +36 1 209 0555 x6654, Fax +36 1 372 2927
E-mail lityi@sas.elte.hu

W. Li
UCLA
7127 Math Sciences Bldg
405 Hilgard Avenue
Los Angeles, CA, 90095, USA
E-mail: moonli@atmos.ucla.edu

Commission J

J. W. M. Baars
Mm-astronomy
Max Planck Institute for Radio Astronomy
Auf dem Hügel 69
53121 Bonn, GERMANY
Tel: +49-228-525303
E-mail: jacobbaars@arcor.de

Commission K

P. Mojabi
Room E3-504B, EITC Building
Electrical and Computer Engineering Department
University of Manitoba
Winnipeg, R3T5V6, CANADA
Tel: +1 204 474 6754 , Fax: +1 204 261 4639
E-mail: Puyan.Mojabi@umanitoba.ca

Associate Editors, Columns

Book Reviews

G. Trichopoulos
Electrical, Computer & Energy Engineering ISTB4 555D
Arizona State University
781 E Terrace Road, Tempe, AZ, 85287 USA
Tel: +1 (614) 364-2090
E-mail: gtrichop@asu.edu

Historical Papers

J. D. Mathews
Communications and Space Sciences Lab (CSSL)
The Pennsylvania State University
323A, EE East
University Park, PA 16802-2707, USA
Tel: +1(814) 777-5875, Fax: +1 814 863 8457
E-mail: JDMathews@psu.edu

Et Cetera

T. Akgül
Dept. of Electronics and Communications Engineering
Telecommunications Division
Istanbul Technical University
80626 Maslak Istanbul, TURKEY
Tel: +90 212 285 3605, Fax: +90 212 285 3565
E-mail: tayfun.akgul@ieee.org

Women in Radio Science

A. Pellinen-Wannberg
Department of Physics and Swedish Institute of Space Physics
Umeå University
S-90187 Umeå, Sweden
Tel: +46 90 786 7492
E-mail: asta.pellinen-wannberg@umu.se

Ethically Speaking

Randy L. Haupt
Colorado School of Mines
Brown Building 249
1510 Illinois Street, Golden, CO 80401 USA
Tel: +1 (303) 273 3721
E-mail: rhaupt@mines.edu

Solution Box

Ö. Ergül
Department of Electrical and Electronics Engineering
Middle East Technical University
TR-06800, Ankara, Turkey
E-mail: ozgur.ergul@eee.metu.edu.tr

Telecommunications Health & Safety

J. C. Lin
University of Illinois at Chicago
851 South Morgan Street, M/C 154
Chicago, IL 60607-7053 USA
Tel: +1 312 413 1052, Fax: +1 312 996 6465
E-mail: lin@uic.edu

Historical Column

G. Pelosi
Department of Information Engineering
University of Florence
Via di S. Marta, 3, 50139 Florence, Italy
E-mail: giuseppe.pelosi@unifi.it

Early Career Representative Column

S. J. Wijnholds
Netherlands Institute for Radio Astronomy
Oude Hoogeveensedijk 4
7991 PD Dwingeloo, The Netherlands
E-mail: wijnholds@astron.nl

URSI Officers and Secretariat

Current Officers triennium 2014-2017

President

P. S. Cannon
Gisbert Kapp Building
University of Birmingham
Edgbaston , Birmingham, B15 2TT,
UNITED KINGDOM
Tel: +44 (0) 7990 564772
Fax: +44 (0)121 414 4323
E-mail: p.cannon@bham.ac.uk
president@ursi.org

Vice President

M. Ando
Dept. of Electrical & Electronic Eng.
Graduate School of Science and Eng.
Tokyo Institute of Technology
S3-19, 2-12-1 O-okayama, Meguro
Tokyo 152-8552
JAPAN
Tel: +81 3 5734-2563
Fax: +81 3 5734-2901
E-mail: mando@antenna.ee.titech.ac.jp

Past President

P. Wilkinson
Bureau of Meteorology
P.O. Box 1386
Haymarket, NSW 1240
AUSTRALIA
Tel: +61 2-9213 8003
Fax: +61 2-9213 8060
E-mail: p.wilkinson@bom.gov.au

Vice President

Y. M. M. Antar
Electrical Engineering Department
Royal Military College
POB 17000, Station Forces
Kingston, ON K7K 7B4
CANADA
Tel: +1-613 541-6000 ext.6403
Fax: +1-613 544-8107
E-mail: antar-y@rmc.ca

Secretary General

P. Lagasse
URSI Secretariat
Ghent University - INTEC
Technologiepark - Zwijnaarde 15
B-9052 Gent
BELGIUM
Tel: +32 9-264 33 20
Fax: +32 9-264 42 88
E-mail: lagasse@intec.ugent.be

Vice President

U. S. Inan
Director, STAR Laboratory
Electrical Eng. Dept
Stanford University
Packard Bldg. Rm. 355
350 Serra Mall
Stanford, CA 94305, USA
Tel: +1-650 723-4994
Fax: +1-650 723-9251
E-mail: inan@stanford.edu
uinan@ku.edu.tr

Vice President

S. Ananthakrishnan
Electronic Science Department
Pune University
Ganeshkhind, Pune 411007
INDIA
Tel: +91 20 2569 9841
Fax: +91 20 6521 4552
E-mail: subra.anan@gmail.com

URSI Secretariat

Secretary General

P. Lagasse
URSI Secretariat
Ghent University - INTEC
Technologiepark - Zwijnaarde 15
B-9052 Gent
BELGIUM
Tel: +32 9-264 33 20
Fax: +32 9-264 42 88
E-mail: lagasse@intec.ugent.be

Assistant Secretary General AP-RASC

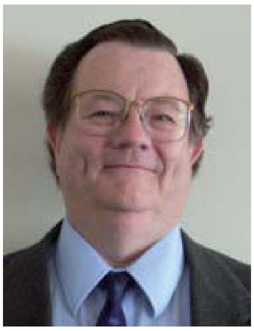
K. Kobayashi
Dept. of Electr and Commun. Eng,
Chuo University
1-13-27 Kasuga, Bunkyo-ku
Tokyo, 112-8551
JAPAN
Tel: +81 3 3817 1846/69
Fax: +81 3 3817 1847

Assistant Secretary General

P. Van Daele
INTEC- IBBT
Ghent University
Technologiepark - Zwijnaarde 15
B-9052 Gent
BELGIUM
Tel: +32 9 331 49 06
Fax +32 9 331 48 99
E-mail peter.vandaele@intec.Ugent.be

Executive Secretary

I. Heleu
URSI Secretariat
Ghent University - INTEC
Technologiepark - Zwijnaarde 15
B-9052 Gent
BELGIUM
Tel. +32 9-264.33.20
Fax +32 9-264.42.88
E-mail info@ursi.org



Assistant Secretary General Publications & GASS

W.R. Stone
840 Armada Terrace
San Diego, CA 92106
USA
Tel: +1-619 222 1915
Fax: +1-619 222 1606
E-mail: r.stone@ieee.org

Administrative Secretary

I. Lievens
URSI Secretariat
Ghent University - INTEC
Technologiepark - Zwijnaarde 15
B-9052 Gent
BELGIUM
Tel: +32 9-264.33.20
Fax: +32 9-264.42.88
E-mail: ingeursi@intec.ugent.be

Assistant Secretary General AT-RASC

P. L. E. Uslenghi
Dept. of ECE (MC 154)
University of Illinois at Chicago 851
S. Morgan Street
Chicago, IL 60607-7053
USA
Tel: +1 312 996-6059
Fax: +1 312 996 8664
E-mail: uslenghi@uic.edu

Editor's Comments

Ross Stone
Stoneware Limited
840 Armada Terrace
San Diego, CA 92106, USA
Tel: +1-619 222 1915, Fax: +1-619 222 1606
E-mail: r.stone@ieee.org

Individual Membership in URSI!

For the first time in its almost 100-year history, it will now be possible for individual radio scientists to become members of URSI. Historically, the official Members of URSI have been the Member Committees established in a territory by its Academy of Sciences or Research Council, or by a similar institution. Individual membership in URSI will now be available to radio scientists, with substantial benefits, as explained in the announcement by URSI President Paul Cannon in this issue. I urge you to read it, and join!

Our Special Section on Radar

We have a special section on "Some Less-Well-Known Contributions to the Development of Radar: From its Early Conception Until Just After the Second World War." This is a *very* special section! It contains unique and extremely well-researched contributions on aspects of the history of the development and use of radar from France, Ukraine and the former USSR, South Africa, and Hungary. The historical insights are fascinating, and the photographs and figures used to illustrate them are treasures. The editors of this special section, Gaspare Galati and Piet van Genderen, have provided a comprehensive and very interesting introduction to the four papers. This introduction is really a fifth paper, serving to provide background for the topics, and additional historical information in its own right. I won't repeat that introduction here, because you need to read it! We are indebted to the editors and authors for their contributions. I urge you to read these papers. They are outstanding.

Our Other Contributions

In keeping with the historical theme of this issue, George Trichopoulos has brought us J. F. Lemaire's review of Donald Carpenter's book on the history of VLF space radio research at Stanford from 1950 to 1990. A version of the book is available as a PDF download: see my Editor's note accompanying the review.

Be sure to look at Tayfun Akgul's cartoon in the Et Cetera column. You'll enjoy it.

Randy Haupt and his daughter have provided us with some "food for thought" in his Ethically Speaking column. The topic is balancing protection and the costs of that protection. I think you'll find it interesting.

In his Telecommunications Health and Safety column, Jim Lin reports on what he identifies as a potential "game changer" for the understanding of cancers potentially associated with mobile-phone radio-frequency emissions. There are provocative issues associated with this. I urge you to read his column.

In her column on Women in Radio Science, Asta Pellinen-Wannberg brings us an article by Galina Ryabova, from the Tomsk State University, Russia. Prof. Ryabova provides a most interesting look at her career in radio science in a period that started in the Soviet Union and continues in the Russian Federation.

There are calls for papers for several important conferences in this issue. Most importantly, the Web site for the 2017 URSI General Assembly and Scientific Symposium, to be held August 19-26, 2017, in Montréal, Québec, Canada, should be open for accepting papers by the time you receive this issue, or within a week or so thereafter. The submission deadline is January 30, 2017. Information is also provided on the Young Scientists program, and information on the Student Paper Competition is available at www.gass2017.org. You should start preparing for this meeting *now*! I have visited the venue, and it is superb. This is going to be one of the best General Assemblies and Scientific Symposias URSI has ever had, and you will want to be a part of it.

Ross

Announcement of URSI Individual Membership

The URSI Board of Officers is pleased to announce the establishment of Individual Fellowship (FURSI), Membership (MURSI), and Individual Associate Membership (AMURSI). By joining URSI, Individual Associate Members, Members, and Fellows secure recognition with their peers, are better connected to URSI Headquarters, and are better connected to their National Committees. Each can then better provide support to the other. Other benefits include discounted registration fees at URSI conferences (beginning with the 2018 URSI AT-RASC) and at some conferences cosponsored by URSI (beginning with some conferences run by IEEE AP-S), a certificate of membership, and e-mail notification of the availability of the electronic edition of the URSI *Radio Science Bulletin*.

Fellowship is by invitation only. Associate and Membership are by application through the URSI Web site at www.ursi.org, where details of the scheme and criteria for membership can also be found. Those interested are urged to visit the Web site and apply.

Paul Cannon
URSI President

URSI 2017 GASS

XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science

Union Radio Scientifique Internationale

August 19-26, 2017 Montréal, Québec, Canada

Announcement and Call for Papers

The XXXIInd General Assembly and Scientific Symposium (GASS) of the International Union of Radio Science (Union Radio Scientifique Internationale: URSI) will be in Montréal. The XXXIInd GASS will have a scientific program organized around the ten Commissions of URSI, including oral sessions, poster sessions, plenary and public lectures, and tutorials, with both invited and contributed papers. In addition, there will be workshops, short courses, special programs for young scientists, a student paper competition, programs for accompanying persons, and industrial exhibits. More than 1,500 scientists from more than 50 countries are expected to participate. The detailed program, the link to the electronic submission site for papers, the registration form, the application for the Young Scientists program, and hotel information are available on the GASS Web site: **http://www.gass2017.org**

Submission Information

All papers should be submitted electronically via the link provided on the GASS Web site: http://www.gass2017.org. Please consult the symposium Web site for the latest instructions, templates, and sample formats. Accepted papers that are presented at the GASS may be submitted for posting to IEEE Xplore if the author chooses.

Important Deadlines: Paper submission: January 30, 2017
Acceptance Notification: March 20, 2017

Topics of Interest

Commission A: Electromagnetic Metrology
Commission B: Fields and Waves
Commission C: Radiocommunication and Signal Processing Systems
Commission D: Electronics and Photonics
Commission E: Electromagnetic Environment and Interference
Commission F: Wave Propagation and Remote Sensing
Commission G: Ionospheric Radio and Propagation
Commission H: Waves in Plasmas
Commission J: Radio Astronomy
Commission K: Electromagnetics in Biology and Medicine

Young Scientists Program and Student Paper Competition

A limited number of awards are available to assist young scientists from both developed and developing countries to attend the GASS. Information on this program and on the Student Paper Competition is available on the Web site.

Contact

For all questions related to paper submissions for the GASS, please contact the URSI Secretariat: gass@ursi.org
For all questions related to registration and attendance at the GASS, please see the GASS2017 Web site:

www.gass2017.org

AWARDS FOR YOUNG SCIENTISTS

CONDITIONS

A limited number of awards are available to assist young scientists from both developed and developing countries to attend the General Assembly and Scientific Symposium of URSI.

To qualify for an award the applicant:

1. must be less than 35 years old on September 1 of the year (2017) of the URSI General Assembly and Scientific Symposium;
2. should have a paper, of which he or she is the principal author, submitted and accepted for oral or poster presentation at a regular session of the General Assembly and Scientific Symposium.

Applicants should also be interested in promoting contacts between developed and developing countries. Applicants from all over the world are welcome, including from regions that do not (yet) belong to URSI. All successful applicants are expected to participate fully in the scientific activities of the General Assembly and Scientific Symposium. They will receive free registration, and financial support for board and lodging at the General Assembly and Scientific Symposium. Limited funds will also be available as a contribution to the travel costs of young scientists from developing countries.

The application needs to be done electronically by going to the same Web site used for the submission of abstracts/papers via **http://www.gass2017.org**. The deadline for paper submission for the URSI GASS2017 in Montréal is **30 January 2017**.

A Web-based form will appear when applicants check "Young Scientist paper" at the time they submit their paper. All Young Scientists must submit their paper(s) and this application together with a CV and a list of publications in PDF format to the GA submission Web site.

Applications will be assessed by the URSI Young Scientist Committee taking account of the national ranking of the application and the technical evaluation of the abstract by the relevant URSI Commission. Awards will be announced on 1 May 2017 on the URSI Web site.

For more information about URSI, the General Assembly and Scientific Symposium and the activities of URSI Commissions, please look at the URSI Web site at: http://www.ursi.org and the GASS 2017 Web site at http://www.gass2017.org.

If you need more information concerning the Young Scientist Program, please contact:

The URSI Secretariat
Ghent University/INTEC
Technologiepark-Zwijnaarde 15
B-9052 Gent
Belgium
E-mail: ingeursi@intec.ugent.be

Introduction to the Special Section on Some Less-Well-Known Contributions to the Development of Radar: From its Early Conception Until Just After the Second World War

***Gaspare Galati*[1] *and Piet van Genderen*[2]**

[1]Tor Vergata University
Via del Politecnico 1 - 00133 Roma, Italy
E-mail: gaspare.galati@uniroma2.it

[2]Technical University of Delft
Postbus 5, 2600 AA Delft, The Netherlands
E-mail: P.vanGenderen@tudelft.nl

Abstract

The invention of radar is 112 years old. A continuing interest has been and is being addressed in the long history of radar, with many old as well as recent publications. However, historical data on radar research and development are spread over many archives in the many nations where the independent and secret development of military radars almost simultaneously started in the 1930s, leaving important material still to be analyzed in both national and private archives. Moreover, unreliable and biased documents exist on this sensitive topic, calling for a wise usage of the written material. As a result of recent and careful archive research (and a result of some personal interviews), done by leading radar experts from four different nations, this special section presents numerous interesting, less-known (in some cases, unknown) elements concerning the development of radar before and during the Second World War (WW II) in France, Ukraine (and former USSR), South Africa, and Hungary.

1. On the Origins of Radar

The main lines of the history of radar are well known, especially concerning the key period that started in the early 1930s. In fact, the rise of Hitler into power (followed by the rearmament of Germany) gave a tremendous push to the development of effective, operational military radars. The climax was reached immediately before and during WW II, with hectic research, development, and operational activities for many types of radar (including new air-defense, fire-control, and naval, as well as airborne, radars).

Most of the related literature originated from the United Kingdom and from the United States of America, the winners of WW II. Much less of the literature came from the nations on the other side (i.e., Germany, Japan, and their allies, including Italy until the Italian armistice of September 8, 1943). This literature was mainly produced in some well-defined periods after WW II: directly after the war (some books or papers were first-hand accounts by the key persons involved in radar development), in the 1980s, and in 2004, the *centennial* of radar (as well as some years later, until today). In fact, it was only many years after the WW II period that everybody understood that the very early beginning of radar was with the *Telemobiloskop*. This apparatus was invented, and built as a prototype, in 1904 by Christian Hülsmeyer, with the aim of installing it on vessels for collision-avoidance purposes. This significant achievement unfortunately was only documented in a few patent applications [1, 2]; a large and updated list of references on the whole history of radar can be found in [3-7].

Radar was then a "forgotten invention" until the real breakthrough in the 1930s, when electro-technology had advanced, in particular in the domains of high-power radiofrequency generators, and of very sensitive receivers. At the same time (around 1933-1935), the operational benefits of radiolocation (versus optical and acoustic location) were understood and assessed, leading to a kind of "rediscovery" of the concept embodied into the *Telemobiloskop*. Such a "simultaneous reinvention" had different names in the many nations independently involved: *radio direction finder* (RDF) in the United Kingdom; *Dezimeter-Telegraphie* (DeTe), and later *Funkmeß* (FuMG, FuMO), in Germany; *détection electro magnetique* (DEM) in France; *radio echo equipment* or *pulse radio equipment* in the USA; *radiotelemetro* (RaRo) in Italy, *radio locator* in the USSR; and so on. It was only since the end of 1940 that the term *RADAR* (*Ra*dio *D*etection *a*nd *R*anging), proposed in November 1940 by Lieutenant Commanders F. R. Furth and S. M. Tucker of the US Navy, came into use. The word "radar" quickly came into general use, although the British retained the terms "radiolocation" and "RDF" for their work in this field until 1943, when "radar" was adopted through international agreement. Each nation worked practically alone, with the noticeable exception of the technology transfer started in 1941 from the United Kingdom to the USA and Canada, and to the Dominion nations including, as described in this special section, South Africa. On the opposite side, i.e., among the Axis powers, the technology exchanges were very limited, certainly within Europe. Technical-information transfer from Germany, the technically most advanced Axis nation, to its allied nations was practically nil.

One of the major technological developments supporting a significant leap forward in the development of operational, compact, and high-power radars during WW II was of course the invention of the *high-power cavity magnetron*. Much has been said about who invented this device. In 1953, this led Wathen to state, "As many agencies had become involved in magnetron research by the end of 1942, it is difficult, indeed, to trace from the literature the true origin of various discoveries and inventions" [8]. Moreover, a dedicated conference was held in 2010 on the 70th anniversary of the high-power cavity magnetron [9]. The cavity magnetron may surely be called a *simultaneous invention with many fathers* [10]. The concept of multiple discovery (also known as simultaneous invention) is the hypothesis that very often, real scientific discoveries and inventions are made independently – and more or less simultaneously – by different scientists and inventors.

In the history of science and technology, it is often found that scientists and engineers from many countries were doing experiments with technology and performing measurements, quite a few with surprising and stimulating outcomes. Such outcomes were not always appreciated for their potential at the time. The same applies to radar, itself: at the time of the breakthrough of radar, i.e., the mid-1930s, the development of radar was a military activity, pursued under strict secrecy by at least ten different nations, with two main development lines: one on the side of the Allies, and the other in Nazi Germany. We could comment that although these two lines are well documented [3-7, 10, 11], the early developments in other countries became known in the public domain – sometimes partly and anyway later – with a rather delayed pace. One aim of this special section is to try to cover this gap, in conjunction with the most recent publications (see, for instance, [12-17]), showing a continuing interest in this particular section of the history of technology.

Knowledge of the reasons for the aforementioned late disclosure of radar-related inventions (some arriving at a complete operational radar set; some remaining at the technological but not-yet-operational level) is uncertain. Maybe countries other than those competing in either of the two main lines of development were "in the wings of the theater" of the development of radar: not directly visible to the spectators, but still participating, aware and ready to join the play. Anyway, there is no doubt that – similarly to the cavity magnetron – radar was a simultaneous development, as well.

2. On the Literature Related to the History of Radar

In reality, it turns out not to be true that everything (or, at least, the most significant contributions) on the early development of radar has already been said in open and reliable sources. For instance, it has to be pointed out that in the Preface of [3] it was clearly written: "The work in the United Kingdom is then chosen for more detailed attention." Concurrently with that, in [3], only 21 pages (out of 325 pages) were dedicated to the "Beginning of Radar" in all of the following nations: France, Italy, Japan, Russia (more precisely, the Soviet Union or USSR), Holland, and Hungary, while nothing was said in [3] about South Africa, Canada, Australia, and New Zealand.

Moreover, so many contributions have been presented in the literature from a biased point of view. For example, in [11], at page 127, one may read: "France, Germany, Japan and the US had each in their different ways investigated the detection of aircraft from reflected electromagnetic waves....It was only in Britain that the significance of the technique was realized at the highest level." The interested reader is referred to [18] for the instructional history of the *rise and fall* of radar activities in Canada during and just after the WW II period.

Scanning the rich literature about the history of radar, some early exploratory developments – precursors to the device later called "radar" – can be found. They concern developments with a clear objective but an uncertain outcome, as already mentioned above. This is what had to be expected at such an early stage, with many efforts exploring technology, experimenting whether or not any operational benefit could be achieved. Quoting again from Swords [3],

> ...actual radars did not...directly emerge from visionary writing...but from people who...went ahead and discovered experimentally that aircraft and ships had significant scattering cross-sections. Under the pressure

of the Second World War, all manner of radar systems emerged. The diversification was principally in function and frequency.

There could be a reason for the transfer – or, sometimes, the lack of transfer – of insight in technology and application potential from the technical community to the application domains. One reason has nothing to do with the competences of scientists and engineers, but with the structure of the communication between the communities contributing to the technical developments and the communities using these developments. Skolnik [19] observed this as follows:

> The communication problem is not that we don't know what is going on in other Services, but has been in getting the message of the technical radar community to a higher (decision) level in the military management chain where actions can be taken. In World War II this problem didn't exist in the US because civilians seemed to have more control of the direction of military R&D. If you look at the history of military technology in World War II, you will find that those countries which had civilians in control of the new directions in technology (the UK and the US) were far more successful in introducing new technology as compared to the totalitarian countries (Germany, Japan, and Italy) where the military were in direct charge of R&D.

A similar comment was expressed by Sir Robert Watson-Watt in a discussion of a series of papers on the development of the cavity magnetron in 1947 [20]:

> It was a very great triumph of individual thinking and of the merging of individual conceptions that produced the work which has been described in these papers, which deal primarily with the work carried out at Wembley and other establishments of the production industry. Even then, however, there was a missing element. The availability of skilled and sceptical [sic] critics in the Government research establishments was, I believe, the third essential contribution to the most fascinating story that is given in the papers.

However, when reading the words by Skolnik and Watson-Watt, one should not forget that their perspective, as said before, remained that of the winners of WW II, not putting in the right perspective some very advanced achievements by the hostile nations. In reality, the strongest of them, Germany, before WW II and during the first years of the war, in spite of its "walls" between technology developers and military leadership, developed some of the most advanced radar techniques in the world [7, 14, 17, 21]. These included large reflector antennas for precise angular tracking (Würzburg Riese), steerable phased-array antennas (Mammut), anti-chaff filtering, stealth, three-dimensional radar (Wassermann), radar on submarines, OTH radar (See Elefant, Knickebein J), imaging radar at K band, and more.

Anyway, under the conditions in which military systems were firstly developed, communication did follow the present line via publications in the open, but, rather, a more complicated way via committees, working parties, notes, meetings, demonstrations, etc. Generally, these types of communication were not in open archives, and were partly accessible (much) later. In particular, some radar developments were known at a late stage, i.e., since the archives of World War II have become accessible to historians. Several interesting details were disclosed after analysis of notes and reports in these now-open archives (e.g., [22]). However, other maybe-even-more-interesting aspects were lost forever due to the (voluntary or not) destruction of the then-secret documents in wartime. For example, [7] showed that the original documents by Ugo Tiberio and Algeri Marino, on the birth of Italian naval and airborne radar, were destroyed in Livorno and in Guidonia, respectively, not to mention the huge devastations, often by fire, in Germany in 1945.

3. Critical Aspects and Lessons Learned Concerning the History of Radar

When addressing the literature on the history of radar, one must bear in mind that it is not free from errors. Publications must be "used with care," double-checks generally being needed. Some errors were simply due to a pure lack of care, while others were inspired by a particular intention, and not by a search for historical truth (e.g., due to a political bias, such as sympathy with Fascism, or friendship or even kinship), with all the possible balances between those extremes. A very recent example of the effect of kinship – or better, "filial love" – was found in [23], a short paper with an interview of Marconi's daughter Elettra, married Giovanelli. This paper contained the *old story*[1] according to which Marconi invented radar and built "the first radar station in the world...in 1935 in Santa Marinella." As a consequence, the paper adds that "without the radar of Marconi, in 1941 the Battle of Britain against the Nazis would have almost certainly been lost." Unfortunately, all of that has been shown (*inter alia*, in [7, pp. 6-11]) to be fully false, together with the claim, also in [23], that the late invention by Marconi was "the extraction of gold from seawater" [sic!].

---

[1] This *story* is also present in some Italian papers and books of the after-war period. They are referenced in [7, p. 8, 385]. Some of them are readily attributed to nostalgic authors oriented to the past Fascist regime, a regime strongly supported by Guglielmo Marconi from its beginning until Marconi's death. A deeper discussion in Italian about Marconi, with a very rare photo of him bearing the *fez*, can be found at http://radarlab.uniroma2.it/stscradar/marconi.pdf.

A first lesson learned by studying the history of radar therefore tells us to please dig in historical archives (some of them may not yet be disclosed), to dust off old statements, and only then – and possibly with a significant delay – to arrive at fair conclusions, and to publish.

A second lesson might be that important inventions (such as radar and, much more recently, for instance, digital processing of signals, the Internet, cellular telephony, Web-based services, intelligent personal terminals,...) arrive without advertisement. One could argue that the inventors (the engineers) are too busy to find time to advertise, and, maybe, do not even like to do. For example, this is to say that when signal processing became digital (first in radar, later in communications equipment), nobody advertised this revolutionary change; it simply happened. In general, engineers do not care about advertising. On the other hand, scientists, mostly physicists, seem to be more focused on publicity. Sometimes this situation has produced "long-time advertised inventions" that after decades of advertisements didn't arrive at any practical use. Many more examples can be found. They include the quantum distribution of cryptographic keys using entangled photons, a proposed technique not leading, in 30 years, to any real system (one of the related protocols is the BB-84 protocol, published by C. H. Bennett and G. Brassard in 1984, followed by E91 by Ekert in 1991). Other related examples of "long-time-advertised inventions" are quantum computers, recently followed by some empty words on "quantum radar," not to mention that the well-known nuclear-fusion reactors never arrived, in a half century, at any production of power.

Organizing an invention is probably self-contradictory, as engineers' experience tells us that the best products were invented when the ideas in the inventor's minds were internally "ignited," i.e., not at organized events. It seems that the invention was in the mind of the inventor for a long while, maturing by every new piece of technology or user need that the (future) inventor observed, until its "sparking" in some unexpected moment. The related results may be hard to forecast: hence, the prevalence of "effective not-advertised inventions" over "advertised ineffective inventions."

4. Scanning this Special Section

Along the above-mentioned philosophical line related to the development of radar in the period mostly considered in this special section, one might consider four different types of overall activity:

1. Development of radar going on at a high pace, driven by success (examples: United Kingdom, USA, and, with some delay after 1940, Germany).
2. Development of technologies useful for radar either directly or indirectly, but frustrated, and so not encouraged, by the cause of the war (France and Netherlands after the German invasion, and Italy after September, 1943).
3. Development of radar at a pace that was lower, but still leading to fielded systems (examples: USSR including Ukraine, Italy).
4. Development of radar in countries that were dependent companions to the key players (South Africa dependent on the United Kingdom, Hungary dependent on Germany, but both having their own design effort as a backup).

Keeping in mind those thoughts, we have set up with our best effort this special section on the history of radar, reporting on "less-known aspects" of the development of radar all over the world. There could be many more papers as candidates for this special section: the history of radar is quite rich, although, as explained before, not always clear. In this issue, one will find publications on the autonomous developments by France [24] and by Ukraine/USSR [25]. Two more papers describe developments made with a dedicated link with either England or with Germany, i.e. in South Africa [26] and in Hungary [27], respectively. These four papers are rich in terms of original data and drawings, obtained by careful research in archives.

To be more precise, the paper by Yves Blanchard, "A French Pre-WWII Attempt at an Air-Warning Radar: Pierre David's Electromagnetic Barriers" [24], is dedicated to a kind of early "forward-scattering" radar, the so-called Pierre David Radio Barriers. They were designated as the "*maille en Z*" (mesh in a Z shape), and were able to retrieve multidimensional localization details of aircraft in a forward-scatter multi-static arrangement. In many respects, today this would rank under the umbrella of the class of radar designs called MIMO (multiple-input, multiple-output). If computational tools had been available in the field at the time of the David Barrier, the system would have readily been recognized as useful and operable in the field. However, such tools did not exist at the time. Just as Klein Heidelberg was a hitchhiking bistatic radar system "avant la lettre" [22], the Pierre David Electromagnetic Barrier was a MIMO system "avant la lettre."

The paper also shows that the pressure of the upcoming war had a very strong impact on the appreciation of research, and on the pressure to arrive (preferably overnight) at useful designs. Visionary and imaginative scientists/engineers and military are rare!

The paper by Felix J. Yanovsky, "Glimpses of Early Radar Developments in Ukraine and the Former Soviet Union" [25], describes the very intensive research and development efforts in the radar area made around the WW II period in the USSR, mostly in Ukraine. They were carried out in the closest secrecy, with a difficult coordination between the many involved governmental and military bodies, and with some "stop and go" phases. It is interesting to note that the first detection of an aircraft in the USSR by their "Rapid" radar happened in July 1934, before the celebrated Daventry trials [3, 7], carried out by the R. A. Watson-Watt team in February 1935. In addition, the early proposal for a radio-detection system for air defense, outlining the basic radar principles, was presented by P. Oshchevpok in the second half of 1933, i.e., more than a year before Watson-Watt's well-known report, written in early 1935, and submitted on February 27, 1935 [3]. The "oscillation" of the USSR authorities between the continuous wave (CW) and the pulse solution was also common to other nations. The competition between the CW and pulsed solutions was present in the radar community for many decades[2].

The history of radar in South Africa hasn't received major attention until today. The former dominion of the UK benefited from the lessons learned by Sir Robert Watson-Watt and his team in the mid-1930s, as is shown in Brian A. Austin's paper, "On the Development of Radar in South Africa and its Use in the Second World War" [26]. Since December 1939, this nation was at war with Nazi Germany. The efforts by the team led by Basil Schonland, a physicist and expert in lightning research, at the Bernard Price Institute of Geophysics (BPI), produced in only three months the prototype of a new radar, the JB0. This showed its first detection on December 16, 1939. The South African team developed its own designs. After the prototype JB0, more designs followed, and JB1 detected bomber aircraft at 80 km. A suite of mobile coastal radars, JB3, was designed and manufactured. In total, 31 JB radars were built and installed, later augmented by a variety British radars. Interesting "ducting" phenomena were observed, causing echoes to be detected from targets very far away.

Finally, the paper by István Balajti and Ferenc Hajdú, "Surprising Findings from the Hungarian Radar Developments in the Era of the Second World War" [27], describes the many intensive radar developments in Hungary. These originated in defense needs, and from the fact that Germany did not supply to allied Hungary either technical information nor adequate radar sets, a situation in some ways similar to Italy before the armistice. Thanks to the leadership of József Jáky, the Hungarian Institute of Military Technology developed the air-surveillance radar *Sas* (Eagle), the fire-control radar *Borbála* (Barbara), the airborne radar *Turul*, and the fighter-control radar *Bagoly* (Owl). These developments (also from the technology point of view) were similar to those of Italy, with its radar called Folaga, *Veltro*, and *Gufo*. By chance, the latter name translates into English as Owl, the same as Bagoly. The paper by Balajti and Hajdú exhibits a wealth of images, drawings, names, and historical facts that have not been previously seen in accessible publications on Hungarian radar development.

5. Comments and Conclusion

Adding interesting details, the papers in this special section confirm that the events prior and during WW II pushed many nations to develop effective radar systems. With the noticeable exception of the Anglo-American cooperation, this was done independently of each other. These systems were based on the ground, along the coast, at sea (including on submarines), and airborne, and were directed to surveillance, antiaircraft fire, guidance of fighters and bombers, and naval operations. Before the advent of the cavity magnetron, the main technological difficulties were in the high-power radio-frequency sources, initially based on existing radio and TV valves. The most practical solution at that time was perhaps the British solution, mostly based on the BBC radio transmitters at HF. Other nations (Germany, Hungary, Italy) preferred to try the VHF band, arriving soon at the "ultra-short waves" of 50 cm to 70 cm. From the overall system point of view, the requirements for air defense (as well as those for the guidance of anti-aircraft and anti-ship artillery) were very clear to all since the 1930s. However, to comply with these requirements, some nations (e.g., France, Italy, and URSS) had a more conservative approach, maintaining for some time the inadequate Earphones, or Sound Mirrors, while the United Kingdom was quicker in substituting for them, once the effectiveness of the radar technique was demonstrated. There were also difficult relationships between armed forces in some nations (Japan, Germany, France) that sometimes slowed down radar developments. In some cases (e.g., Italy), these difficulties were exacerbated by difficult relationships between the customer (e.g., the armed forces, or national military committees) and national industries, and a lack of continuity, thus slowing down development and production. Commenting on this situation after WW II, Watson-Watt was correct in stressing the tripartite cooperation (research, industry, and a competent administration): "Success has many fathers!"

6. References

1. Chr. Hülsmeyer, Patentschrift Nr. 165546, "KLasse 21g, Verfahren um entfernte metallische Gegenstände mittels elektrischer Wellen einem Beobachter zu melden," Düsseldorf, April 30, 1904.

---

[2] These *oscillations* may be also found in the different editions of the perhaps most known textbook on radar systems, by M. I. Skolnik, Introduction to Radar Systems. In fact, looking at the different editions of this book, the first in 1962, the second in 1981, and the third in 2001, one finds the following. Continuous-wave radar was treated in the second edition, Chapter 3, but that part was omitted in the third edition, "...because of the decreasing utilization of this type of radar." Today, continuous-wave radar technology is used in various applications, including marine-navigation, coastal-surveillance, and automotive radars.

2. Chr. Hülsmeyer, Patentschrift Nr. 169154, "Klasse 74d, Verfahren zur Bestimmung der Entfernung von metallischen Gegenständen (Schiffen o.dgl.), deren gegenwart durch das Verfahren nach Patent 165546 festgestelt wird. Zusatz zum Patente 165546 vom 30. April 1904," Düsseldorf, November 11, 1904.

3. S. S. Swords, *Technical History of the Beginnings of RADAR*, London, Peter Peregrinus Ltd., 1986.

4. Y. Blanchard, *Le Radar 1904-2004: Histoire d'un Siècle d'Innovations Techniques et Opérationnelles*," Paris, Ellipses Édition Marketing S.A., 2004.

5. DGON (German Institute of Navigation), *100 Years of Radar – Special Issue – Contributions from Various Countries Describing the Individual Radar Development Processes*, (booklet edited in May 2005 containing eight historical papers), available at http://www.dgon.de.

6. F. O. I. Bremer and P. van Genderen (eds.), *Radar Developments in The Netherlands – 100 Years After Hülsmeyer*, (booklet edited by Thales on the occasion of the European Microwave Week, Amsterdam, 2004).

7. G. Galati, *100 Years of Radar*, Cham, Switzerland, Springer International Publishing AG, 2015.

8. R. L. Wathen, "Genesis of a Gyrator – The Early History of the Magnetron," *Journal of the Franklin Institute*, **255**, 4, April, 1953, pp. 271-287.

9. Proceedings of the 2010 International Conference on the Origins and Evolution of the Cavity Magnetron (CAVMAG), Bournemouth University, England, April 19-20, 2010.

10. Y. Blanchard, G. Galati, and P. van Genderen, "The Cavity Magnetron: Not Just a British Invention," *IEEE Antennas and Propagation Magazine*, **55**, 5, October, 2013, p. 244-254.

11. Ian Goult, *Secret Location – A Witness to the Birth of Radar and its Postwar Influence*, Charleston, South Carolina, The History Press, 2010, ISBN 978-0-7524-5776-5.

12. W. Holpp, "The Century of Radar," Fraunhofer FHR, Wachtberg/Germany, 2004; available at http://www.100-jahre-radar.fraunhofer.de/vortraege/Holpp-The_Century_of_Radar.pdf

13. G. Galati and P. van Genderen, "History of Radar: The Need for Further Analysis and Disclosure," Proceedings of EuRAD 2014, Rome, Paper EuRAD30-01, October 8-10, 2014.

14. Y. Blanchard, "A German Radar Chain, Facing the British Chain Home During WW II," Proceedings of EuRAD 2014, Rome, Paper EuRAD30-02, October 8-10, 2014.

15. H. Rohling, "From Huelsmeyer's Telemobiloskop to the Digital Radar," Proceedings of the European Radar Conference EuRAD 2014, Paper EuRAD30-03, Rome, October 8-10, 2014.

16. G. Galati, "On the Italian Contribution to Radar," Proceedings of the European Radar Conference EuRAD 2014, Paper EuRAD30-04, Rome, October 8-10, 2014.

17. F. Yanovsky, "On the Ukrainian Contribution to Radar," Proceedings of the European Radar Conference EuRAD 2014, Paper EuRAD30-05, Rome, October 8-10, 2014.

18. W. E. Knowles Middleton, *Radar Development in Canada: The Radio Branch of the National Research Council of Canada, 1939-1946*, Waterloo, Ontario, Wilfred Laurier University Press, 1981.

19. M. Geselowitz, "Merrill Skolnik, An Oral History," February 22, 2000, IEEE History Center, Hoboken, NJ, USA, available at http://ethw.org/Oral-History:Merrill_Skolnik.

20. "Discussion on 'The Cavity Magnetron,' 'The High-Power Pulsed Magnetron: A Review of Early Developments,' and 'The High-power Pulsed Magnetron: Development and Design for Radar Applications,' Before the Radio Science Section, 19th November, 1947," *Journal of the IEE, Part III: Radio and Communication Engineering*, **95**, 35, 1948, pp. 130-134.

21. F. Trenkle, *Die deutschen Funkmeßverfahren bis 1945*, Heidelberg, Germany, Hüthig, 1986.

22. H. Griffiths and N. Willis, "Klein Heidelberg – The World's First Modern Bistatic Radar System," *IEEE Transactions on Aerospace and Electronic Systems*, **46**, 4, October 2010.

23. Alfonso Farina and Livio Spinelli, "A Friendly Conversation with Princess Elettra Marconi," *IEEE Aerospace and Engineering Systems Magazine*, November 2015, pp. 29-34.

24. Yves Blanchard, "A French Pre-WWII Attempt at Air-Warning Radar: Pierre David's Electromagnetic Barriers," *Radio Science Bulletin*, No. 358, September 2016, this issue.

25. Felix J. Yanovsky, "Glimpses of Early Radar Developments in Ukraine and the Former Soviet Union," *Radio Science Bulletin*, No. 358, September 2016, this issue.

26. Brian A. Austin, "On the Development of Radar in South Africa and its Use in the Second World War," *Radio Science Bulletin*, No. 358, September 2016, this issue.

27. István Balajti and Ferenc Hajdú, "Surprising Findings from the Hungarian Radar Developments in the Era of the Second World War," *Radio Science Bulletin*, No. 358, September 2016, this issue.

A French Pre-WW II Attempt at Air-Warning Radar: Pierre David's "Electromagnetic Barrier"

Yves Blanchard

Historian, Consulting Engineer
Retired from Thales, Paris, France
E-mail: yvfrancb@club-internet.fr

Abstract

Pierre David, a French pioneer of the 1920s in the VHF domain, is best known for his early work on air defense and detection of aircraft. His approach, which he called DEM (electromagnetic detection), was quite similar to the "beating method." There was experience with this at the same time at the American Naval Research Laboratory (NRL), and this is recognized to have initiated the radar concept in the US. Other developments in Great Britain and more especially in Japan are also discussed. However, David was certainly the person who went the furthest in field applications to develop a French operational system that could meet the pressing threat of German Nazi aviation. The results of the full-scale experiments of his "Electromagnetic Barriers" are described from test reports of the French Air Force, unpublished to this day. A "Compagnie de Guet Electromagnétique" (Electromagnetic Warning Company) was established to build a Chain Home "à la Française" along the German border. The outbreak of the war did not allow its deployment, apart from a limited facility in the Marseille region. However, the principles that David had established to find an efficient solution for a true three-dimensional localization (leading to the "Maille en Z" method) prefigured the modern approach of generalized multi-static sensor systems, which is popularized today under the MIMO (multi-input multi-output) concept.

1. Introduction

"Radio Detection Finding" (RDF), "Dezimeter Telegraphie" (DeTe) or FunkMessOrtungsGerät (FuMO), "Radio Detector Telemetro" (RDT), "радиоуловитель самолётов" (RUS, Radio Ulovitiel Samaliotov): This extended list of code names used throughout the world before the adoption of the universal acronym RADAR (radio detection and ranging) is an eloquent illustration of the great variety of technical developments undertaken in this field between the wars, in all industrialized countries [1, 2]. As for France, it is known that two distinct approaches were explored very early [3, 4]. The first one resulted from advanced studies of the CSF company on the magnetron: the history of the first centimetric radar, which equipped the liner *Normandy* in 1935 [5], was recently recalled in various papers [6, 7]. Here, we will look at the second approach, initiated around 1925 by the French engineer Pierre David. This has to be placed in the context of the period, and compared to other implementations in the USA, Great Britain, or Japan. These systems, typically working on a bistatic scheme, were generally limited to an alerting function. However, David tried to give them a real capability for three-dimensional localization, to be inserted in a global project of air defense. The outbreak of WW II did not allow carrying out the full implementation, but the interest given today to multi-static systems sheds a new light on the premonitory aspects of David's "Electromagnetic Barriers."

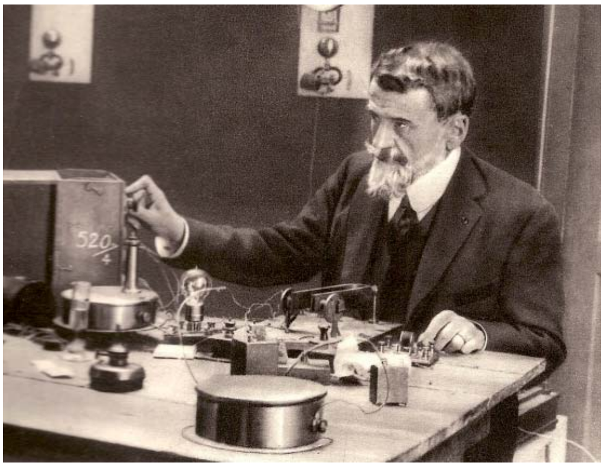


Figure 1. General Ferrié (about 1930).

2. Pierre David, Disciple of General Ferrié, and French Pioneer of Electromagnetic Detection

Pierre David (1897-1987), graduated in 1920 from the Ecole Polytechnique and also received the Doctor of Science. Like most pioneers of the French radio industry, he began his career in the famous Laboratoire Central de TSF [Central Laboratory of Wireless-Telegraphy]. This was created after WW I by General Gustave Ferrié (1868-1932) (Figure 1) to avoid the dispersion of his team of the Radiotélégraphie Militaire [Military Radiotelegraphy], and to save the high technical potential reached during wartime. At that time, Ferrié was recognized throughout the world as one of the most important initiators of radio technology. He had acquired a dominant position in the history of this field, for instance, as a founding member of URSI, and as first President of the French URSI Committee. His new laboratory was given a mixed status, involving both civilian and military staff, under the joint supervision of the War and PTT ministries. Its mission was to "combine scientific research with practical experiments and implementation of prototype devices." In 1931 it became the LNR, Laboratoire National de Radioélectricité [National Radioelectricity Laboratory].

David (Figure 2) was one of the four civil engineers who had served since 1920 in the first nucleus of the Ferrié team. With his colleague, Professor René Mesny, he engaged in his first research towards what they called the "very short waves." Returning to the frequency range used by Hertz (while Marconi's wireless telegraphy needed longer and longer waves, as long as 30 km by the end of WW I) was not just a matter of pure curiosity! They were looking to replace radio links that indiscriminately flooded the whole space with directive beams working from point to point, as in an optical connection. In 1923, René Mesny went right down to wavelengths of 1.2 m, using a symmetrical assembly of two classical triodes. With Pierre David, he organized a public demonstration of an experimental radio link at the Physics and Wireless Telegraphy Exhibition of Paris [8], showing good telephone communication on a 2 km phone link. The wavelength was still close to one meter, and the range was quite short, but the purpose was clear. Through slow but steady progress, these pioneers reached the borders of the *microwave* domain, opening the way to other unexpected applications that were still to come – such as radar.

It was in this field that David proved to be a real visionary. As soon as 1925, he was the first at the Laboratoire National de Radioélectricité to take interest in the problem of aircraft detection, at a time when the question was not yet of great priority.

During propagation tests on metric waves in June 1925, he observed that the reception was frequently disturbed by electromagnetic noises coming from nearby combustion engines – cars or motorbikes on the ground – and also aircraft flying within a 500 m radius. Reporting this to General Ferrié, he proposed to test detection of planes by "listening" to the noises produced by the electric ignition of their engines. He probably ignored that such an idea had already been suggested by Major E. H. Armstrong of the US Signal Corps, when Armstrong served in 1918 as a radio expert in the American Expeditionary Force in France. As a matter of fact, Armstrong's fame was actually based on his invention of the superheterodyne receiver. David was allowed to try a field experiment, which was made at Le Bourget airport on March 30, 1927, with the assistance of Prof. Mesny and Captain Nicol from the French Air Force. With a super-reactive receiver, it was found that some planes were detected at 3 km, but some others were not detected at all. It was then decided to continue the study in better conditions, with a directive antenna and a radio-goniometric receiver, on the Palivestre facility, near Toulon.

For reasons of aircraft availability, this second campaign was postponed until the spring of 1930. The measurements were performed by Messieurs David and Maginot from April 1 to 10, with a lot of various aircraft. Three types of antennas were used: an antenna of five horizontal wires, each 15 m long, horizontally fanned out at 4 m above the ground; an Adcock-type antenna with four vertical dipoles on a 10 m diameter cylinder, for direction finding (Figure 3); and occasionally, a square frame with sides of 7 m. In every test, the receiver was a super-reactive "universal E20," tuned to wavelengths between 12 m and 25 m.

Figure 2. Pierre David (l) presenting Ferrié's prize to M. H. Carpentier (r) in 1969.

The new results confirmed the 1927 results, with a slight improvement. All aircraft were listened to, at ranges that could likely be increased with a more-sensitive receiver. However, the source location remained quite imprecise, despite the use of the goniometer and various attempts to improve the location [9]. (It can be added that some infrared detection was also simultaneously performed, with even poorer results.)

The report concluded with the possibility of further improvements. However, even before the second test campaign, David had understood that these efforts would be useless. The countermeasure was too obvious, and already on the way: as these ignition noises confused the onboard radio links as well, engines were shielded more and more to suppress them. He concluded that, "the tests did not prove a sufficient military value, due to the easiness to stop any detection by shielding the magnetos," and the study was abandoned.

However, the matter was not! As he felt his semi-failure was an incentive, David now focused his mind on this exclusive problem of aircraft detection. His decisive idea came out then, much richer than any previous idea, and it heralded all the further developments of "electro-magnetic detection" in France. David suggested that even though new shielding could prevent any electrical radiation, it would still be possible, using his own words, "*to force the planes to radiate*," in some way despite themselves "*by taking them into the field of a beam of HF radio waves.*" A short calculation proved that at metric wavelengths, any aircraft would reflect a sufficient part of the received energy to make an echo perceptible by a ground receiver [10].

This quotation deserves a moment of attention. Since Christian Hülsmeyer, it was the first expression of a clear "active-sensing" concept, as opposed to all the "passive systems," either acoustical or optical, considered before. David revived Hülsmeyer's idea, in which the radio transmission had no other purpose than to generate an echo: the idea that made radar a definitively new application of Hertzian radio waves.

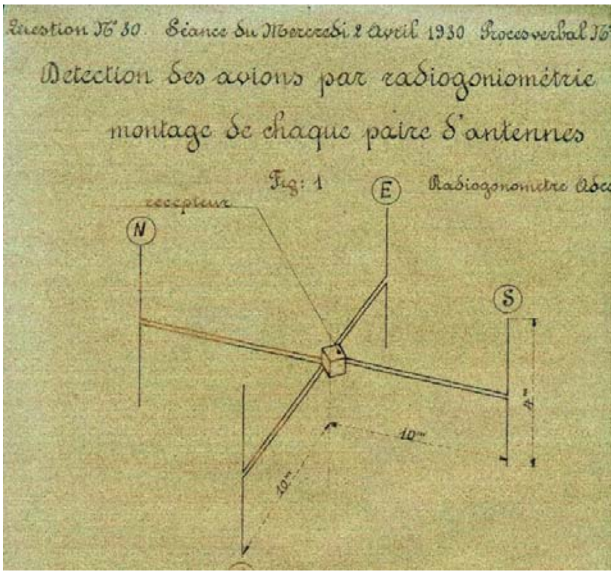


Figure 3a. The Palivestre trials (February 1930): the Adcock antenna [9].

David presented his suggestion to General Ferrié in a memorandum [11], which was sealed in a "*Soleau enveloppe*" (a French method used as a provisional proof of priority of invention, before it could be patented). This document was dated June 5, 1928, and was only reopened in May 1935. It must be seen as the true "birth certificate" of French radar.

Unfortunately, it seems that no copy of this historic memorandum has been preserved. However, we were lucky enough to find a good indication of its contents through a letter from General Challéat, Chief of the Artillery Service of Research, reporting a conversation held between David and Captain Lefranc at the end of 1928 [12]. David already suggested, if the Palivestre tests would be insufficient, to study a new device based on a different principle:

> ...it would give a plane detection through the perturbation it would bring to radio waves emitted by a ground station. This process would be sensitive enough to detect the waves emitted by any type of aircraft, which is an advantage on the current "listening" study.

Challéat was ready to undertake tests in this way, without waiting for the results of the current study.

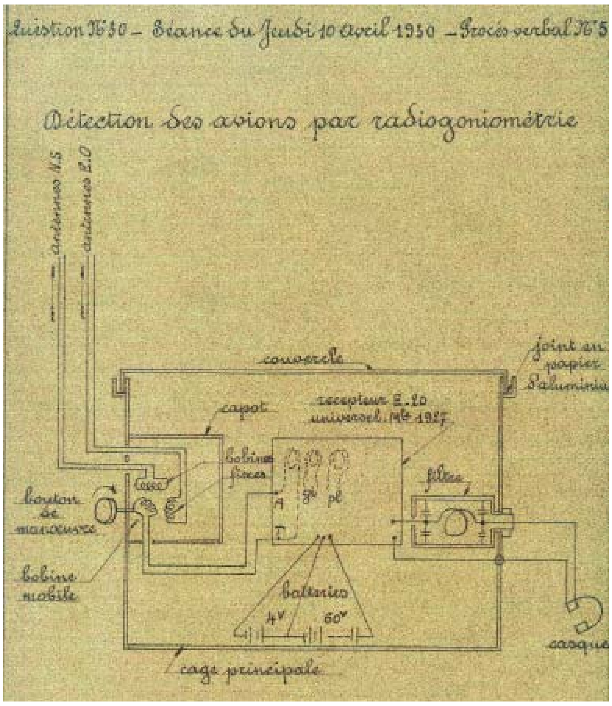


Figure 3b. The Palivestre trials (February 1930): the E20 goniometric receiver [9].

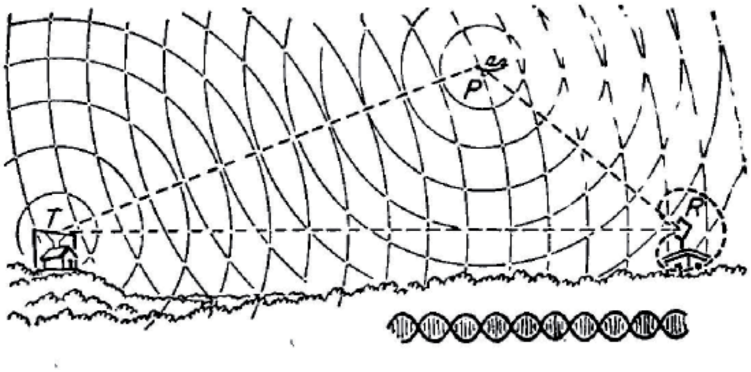


Figure 4. The Naval Research Laboratory beat method [13].

However, despite the urgency, nothing happened in the following years. The inventive process seems to have been slowed down by the lack of an operational need clearly expressed by the military staff, while things moved much faster elsewhere, and particularly in the United States.

3. A Welcome American Reference

An interesting parallel can be drawn with what arose during the same period at the US Naval Research Laboratory (NRL), where quite similar ideas had emerged from 1922 to 1930, at the initiative of two radio engineers, A. Hoyt Taylor and Leo C. Young.

Their story, which has been told by their younger colleague, Robert Page [13], begins in mid-September 1922, on a day where they tested a directive radio link across the Potomac River. Having obtained the correct tone for which they, they were suddenly surprised with an unexpected swell that nearly doubled its normal amplitude, followed by a quasi-extinction, the same process being reversed several times (Figure 4). The affair could have stopped there, and been forgotten as well. However, they noticed that this occurrence had coincided with the passage of a river steamer across their line of sight. As naval engineers, familiar with Navy problems, they immediately thought that this effect could be used to prevent enemy ships from penetrating harbors or fleet formations at night. Their letter to the Navy Bureau of Engineering, suggesting to use this as a "radio alarm", was the first US proposal for the use of radio to detect moving objects in space. It was dated September 27, 1922.

However, nothing resulted until a second "accident," which this time involved an airplane flying overhead. It was observed on June 24, 1930, by the same Leo C. Young and L. A. Hyland. It was then reported to A. G. Taylor, then head of the laboratory. It was clearly identified as a beating phenomenon between the direct signal and a second signal re-radiated from the intruder. Something new was also revealed: if it was not really surprising that a large ship reflected a detectable signal, it was much more unexpected with a small wooden plane!

This time, Taylor took time for further tests with different antennas and frequencies, before transmitting on November 5, 1930, a detailed 11-page report to the Bureau of Engineering. To establish his argument, one month later he organized a demonstration of this radio-detection method, which he called the "*beat method*."

At about the same time, similar views were thus shared by the French Laboratoire National de Radioélectricité and the American Naval Research Laboratory. However, while David's projects were stopped by his superiors in France, for the next three years, from 1931 to 1933, Taylor and Young would pursue their feasibility tests at the secret facility of Dahlgren. Using a 29 MHz, 500 W transmitter, and a receiver separated by about 5500 m across a small hilly area, they succeeded in detecting a small aircraft up to a distance of about 75 km. To finalize the question, a patent, entitled "System for Detecting Objects by Radio," was filed on June 13, 1933 [14]. The affair was then transferred to the Army Signal Corps: at the Naval Research Laboratory, the time had come to give priority to the pulse-radar developments.

This research was conducted in a military secret context. However, the basic phenomenon that had initiated the work was fortuitously observed again in 1932 by civil engineers of the Bell Laboratories, and published in March 1933 in the *IRE Proceedings* [15]. This gave the opportunity of a new departure to Pierre David.

4. David's Efforts to Achieve an Operational System (1934-1935)

This publication in the open literature encountered special attention in France. The paper suggested that the observed effect could be used to detect an aircraft "to unsuspected distances," which was exactly the basis of the proposal registered by Pierre David in his memorandum of June 1928. However, while at that date he could benefit from a real advance of two years before the first observations of Young, he now found himself three years too late!

Moreover, the situation had become less favorable, in the meantime. Since the summer of 1931, the Laboratoire

National de Radioélectricité had been led by Prof. Camille Gutton, a former assistant of Ferrié at the Military Telegraphy during WW I, and then a world expert in ultra-short waves. Quite naturally, he favored those new frequencies in the projects of the laboratory, including the questions of detection – which was clearly premature (the idea would later be developed with success by his own son, Henri Gutton, at the CSF company [6]). This led Camille Gutton to a negative attitude towards David's efforts and, to say the least, to not encourage David. This was an attitude that only grew worse with time.

However, this time David held a key argument: from then on it became impossible to maintain that an electrical effect, which had been fortuitously observed by operators who were not looking for it, should be invisible to those who would seek it! The affair rose to the War Ministry through the CEEP, Comité d'Etudes et d'Expériences Physiques [Committee for Studies and Physical Experiments], in charge of steering military research. On January 22, 1934, a ministerial directive asked Gutton and David to quickly undertake the study of electromagnetic detection of aircraft, with the assistance of the French Army's SEMT, Section d'Etude des Matériels de Transmission [Department of Signal Materials Studies], directed by Major Paul Labat (Figure 5).

This support proved decisive. Labat (1900-1944), who had been a schoolfellow of David at the Ecole Polytechnique, pursued a military career that had first led him to the 8th Regiment of Army Engineers at Mont Valérien (once more, in General Ferrié's team). He was known both as an excellent theoretician and as a fine experimenter. His work as head of the Section d'Etude des Matériels de Transmission made him one of the main originators of French radar [16], as will be seen on many other occasions in the course of this history.

The Electromagnetic Barrier designed by David (Figure 6) was directly inspired by the observation of the Bell engineers, and quite similar to the system tested for three years by the US Naval Research Laboratory. A shortwave transmitter (E) and a receiver (R) were installed within reach of the limit of direct transmission. In the absence of any moving obstacle, the direct wave, attenuated only by the ground path, gave a continuous sound. However, when a plane flew over the base, a second reflected signal, shifted in frequency by the Doppler, produced an interference beating. It characterized the passage of a target. In today's terms, we would qualify this arrangement as a "continuous-wave bistatic radar."

Figure 5. P. David (l) and P. Labat (r) with C. Lange from the French PTT (c), Toulon, 1941.

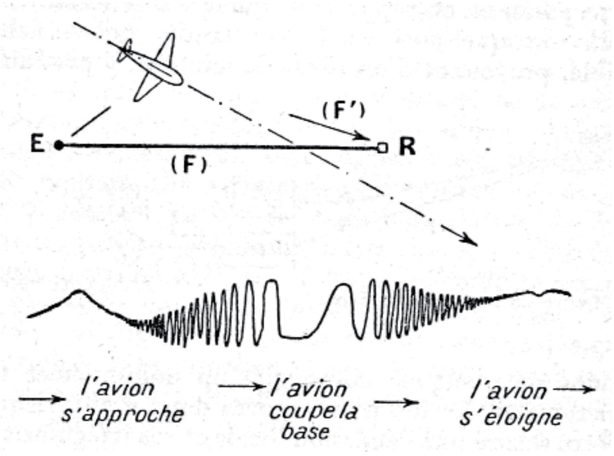


Figure 6. David's "Electromagnetic Barrier" principle [17, p. 84].

4.1 First SEMT Experiments in 1934

The first months of 1934 were dedicated to the development of the new devices needed for the trials. In June 1934, the equipment was installed by Labat's team in a field near Le Bourget airport, which at low cost provided all the desirable "targets of opportunity." Captain Pierre Cazenave, detached by the Air Force, left a description of the experiments [18]. A first attempt, made by Camille Gutton at a 16 cm wavelength, gave no result. This could have been expected, due to a notoriously insufficient sensitivity with 0.1 W power, and due to the narrowness of the beam, which made any search impractical. However, the first sequence with a metric wave ($\lambda = 5$ m with a 50 W power), which took place on June 27, 1934, was immediately successful. When the first plane flew past, beats were clearly heard in the earphone: fast at first, then slowing down until appearing to stop when the plane crossed the transmitter-receiver line, and then accelerating again when it went away, up to distances of 7 km to 8 km for a plane flying at 5000 m.

In November 1934, a second test series was repeated. This time, signals were recorded, to set up a database and to quantify a number of beat-signal parameters, such as frequency, amplitude, time duration, and damping. The next objective was to correlate these measurements with the flight parameters: direction and speed.

4.2 Navy Tests in February 1935

From their side, the French Navy, learning about the Le Bourget results, decided to conduct their own tests by setting up an experimental barrier 19 km long between Toulon and the Giens peninsula. The frequency selected was 52.6 MHz ($\lambda = 5.7$ m). Technical assistance was provided by the LCET, Laboratoire du Centre d'Essais de Toulon [Laboratory of the Navy's Toulon Facility], and the tests took place in February 1935 in the presence of David and Gutton. The first experiment seemed to be a failure, but it was quickly explained: it was a great surprise to find that due to the specific propagation, the range over sea was two or three times the range observed over the ground. This discovery led to reducing the transmission level, or extending the base of measurement. As a result, a work plan was immediately established to look for a future barrier 200 km long, between the mainland and Corsica!

4.3 Recording Tests in July 1935

The time had come to move on to real operational tests. On April 6, 1935, the Air-DAT, Défense Antiaérienne du Territoire [Anti-Aircraft Air Defense], assigned a grant of 70,000 F (about 50,000 € today) to build three new transmitters and six receivers at the ECMR, Etablissement Central du Matériel Radio [Central Establishment of Radio Equipment]. These were to be copies of the prototypes made by David for the previous Navy experiments. Pen recorders were to be bought from Siemens. The equipment ordered had to be delivered at Section d'Etude des Matériels de Transmission by late May.

The 1935 tests were made under the control of the governmental Comité d'Etudes et d'Expériences Physiques, with the participation of three officers detached from the 401th Regiment of Anti-Aircraft Artillery. The Navy also invited delegated Captain Mouren, Chief of the Navy Scientific Research, and M. Laville, engineer and scientific collaborator at the Laboratoire du Centre d'Essais de Toulon (who was present on site from July 15 to 23) to attend the trials.

Originally planned at Metz, near the German border, the trials were finally held in the vicinity of Paris during the summer of 1935, with the assistance of the Le Bourget Air Force and the Etampes Flying School. Different places were selected to try various technical options, and to observe the influence of the ground on the optimal implementation of the transmitting/receiving bases: on the southwestern plateau (Saclay), in the southeast at Brie-Comte-Robert, and in the northeast between Le Bourget and Senlis [19]. With a total of about 30 flights of isolated planes or squadrons, more than 500 passages were recorded and calibrated:

> They confirmed the possibility of detection to higher altitudes, and were used to correlate the observed phenomena with the characteristics of the air passages, and to establish formulas giving the main flight parameters, as route and speed.

The results were very promising: excellent detections were obtained in all cases, by night or with clouded skies as well, on aircraft flying up to 8000 m at a distance of 5 km. The vertical passing was instantly known, the route direction was given to nearly 10 degrees, and the speed was determined to within 10%. The accuracy of the altitude measurement, still poor so far, seemed to be improved by a so-called *contiguous bases method*. All these parameters could be restored in less than 1 hr 30 min by a specialized team using a route calculator. From a practical point of view, the EM Barriers could be moved fairly quickly, on the existing acoustic "watching lines," or to equip new automatic watching lines at a very reasonable cost: namely, of the order of 3000 F per km. From these results, General Duchêne, General Inspector of the Défense Antiaérienne du Territoire, stated: "the Electromagnetic Detection can be seen, without undue anticipation, as the solution for the future to protect against air attacks" [20].

5. Operational Campaigns (1936-1939)

Since the arrival of Hitler to power in 1933, the international situation quickly worsened, causing the anxiety of political leaders and military staffs, particularly faced with the gravity of the air threat. In a sensational and provocative speech, Lord Baldwin had expressed his pessimistic conviction in the British Parliament: "Whatever we do, the bombers will always get through!" When General Duchêne thus concluded his report with: "The problem of an automatic aircraft detection has become crucially important: the efficiency of our defense in a future conflict depends on its solution," David could think that his studies would finally be given a high priority.

5.1 Air-DAT Maneuvers in 1936 and 1937

Things were then sufficiently established to be experimented on with a more operational basis. It was decided to evaluate the military interest in the new technology during aerial maneuvers organized every year during the summer by the Air Force. For two years, in 1936 and 1937, these tests were funded by the Comité d'Etudes et d'Expériences Physiques, and carried out by an Army detachment under the command of Major Labat and Captain Cazenave. David was called in as a reserve captain in charge of the technical direction of the trials.

In August 1936, an E-M base was merely added to a classical acoustic watching line, during the Défense Antiaérienne du Territoire maneuvers in the region of Gien (Loiret). Little is known on the progress of those 1936 trials, but Cazenave reported that 25 passages of aircraft

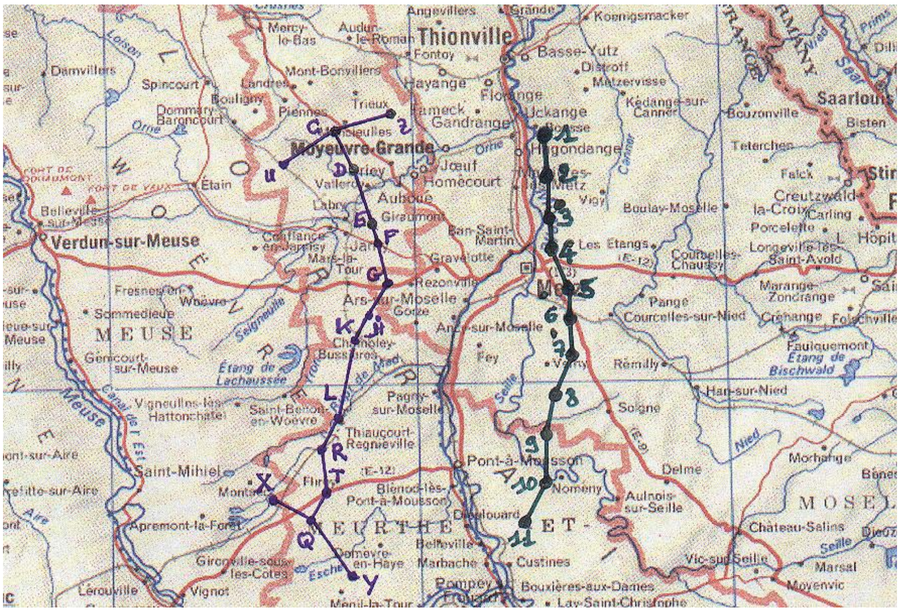


Figure 7. “Krebs” acoustic line experiments, Metz, 1936.

were detected, many of them having escaped the normal watching, and that there was no failure on the DEM side. In all cases, the measured speeds were correct, and in half the cases, the routes were also correct [18].

At the end of the year, new credits were given to the Etablissement Central du Matériel Radio to build 12 modified sets, to be used in June 1937 during the Air- Défense Antiaérienne du Territoire maneuvers in the Reims-Argonne region. With the same organization as in 1936, they were controlled by Lieutenant Nicolardot from the Air Force CEAM, Centre d’Expériences Aériennes Militaires [Center for Military Air Experiments] in Reims, with P. David still acting as a reserve Captain.

The tests took place first in June 1937 in the Reims Centre d’Expériences Aériennes Militaires. Twelve positions were established on two lines in the Argonne area, with satisfying results. According to Captain Cazenave, it was actually the first time that an exercise of fighter interception by night was achieved under DEM guidance. It also seems that a first comparison with an acoustic method was made on August 12, near Mantes. The results of six passages appeared favorable to the DEM, but this success was disputed by supporters of acoustic methods!

These acoustic methods, which should have been rendered obsolete by the arrival of the electro-magnetic detection, were still vigorously defended by most of the Air Force officers. For at least four years, their tactical use had been evaluated in two ways: the so-called “Krebs procedure” for the interception of bombers by day or in illuminated areas; and the “Idatte procedure” by dark night [21]. At the pace of maneuvers that were held only once a year, this could not speed up the matter! To further complicate things, the evaluations were conducted by two different actors: the Centre d’Expériences Aériennes Militaires in Reims, and the CEPDCA, Commission d’Etudes Pratiques de Défense Contre Aéronefs [Commission for Air Defense Practical Studies] in Metz, both ruled by the Air Force, but not without some rivalries of competences. This was typical of a situation that created the technological backwardness of the French Army, and led to the catastrophic defeat of June 1940.

Starting on August 17, 1936, major trials of the Krebs procedure were scheduled at Metz, without DEM [21]. Eleven research stations, equipped with acoustical and optical devices, were staggered between Blettange (southeast of Thionville) and Serrières (southeast of Pont a Mousson) (Figure 7). The results were said to be satisfactory “in favorable weather,” and the report recommended setting up a permanent base around Metz to pursue the trials on more difficult situations. However, the new tests scheduled for 1937 were not ready to be included in the program of the summer maneuvers. They were delayed to September 1937, in the Reims-Laon region, still without DEM.

For its part, in 1936 the Reims Centre d’Expériences Aériennes Militaires tested the Idatte method, also without DEM. The experiments were said to have been satisfactory (32 successful interceptions on 60 passages). However, new trials in 1937 were disappointing, with poorer results: the report concluded that “there was still a long way to go!”

(To conclude this sequence of experiments, it would be worth adding that it gave David the opportunity to evaluate a new procedure that he named the “*Mailles en Z*.” Due to its more exploratory character, it will be detailed in Section 8).

5.2 1937-1938: A New Military Leadership

On October 20, 1937, David's barriers became a purely military matter. The leadership for the future experiments was transferred to the Reims Centre d'Expériences Aériennes Militaires, in order "to finalize its tactical use and to build up its operating procedures, in association or not with other acoustic and/or optical watching methods (Krebs, Idatte)." The collaboration of Captain David was again requested, but this time it was categorically declined by C. Gutton, Chief of the Laboratoire National de Radioélectricité. A few months later, David resigned from his position at the Laboratoire National de Radioélectricité to join the Navy as a scientific advisor. (After the war, he was attached to SHAPE to serve in a similar position, and became Chair of the French URSI Committee in 1951-1952).

As soon as November 1937, the new trials began under the command of Captain Arsac and Lieutenant Nicolardot. The objective was to select the most efficient equipment (built at Laboratoire National de Radioélectricité, Kraemer, SADIR), and to prepare the next maneuvers of 1938. From November 1937 to July 1938, the experiments followed quite continuously, in different locations close to the Army facility of Mourmelon, for instance, between La Veuve and Warmeriville (50 km), between Aguilcourt and Manre (the Suippe Valley, 60 km), and along the Marne, between Sarry and Hautvillers (45 km) (Figure 8).

Numerous tests were made by night, with planes flying with varying speeds, routes, and altitudes. In most cases, the conditions of detection were good above a floor of around 500 m. Some experiments gave rise to comparisons or associations to a Krebs procedure with acoustic devices.

In March, 1938, the international tension suddenly increased with the Nazi coup in Austria, followed by the annexation of the country to Hitler's Reich (Anschluss). It culminated in September with the Sudeten crisis and Hitler's menace to dismember Czechoslovakia, until the Munich Agreement gave a provisional and illusive appeasement.

However, the staffs were now in the logic for preparation for war. Without waiting for the maneuvers scheduled for summer 1938, Captain Arsac was asked to conclude his current tests and the DEM question. His report of July 29, 1938 [22] gave an updated inventory of his new experiments. The report concluded by suggesting some rules of operation, which seemed quite below the previous results acquired in the David period! If used alone, the DEM could only give time and point of passage, with a precision that was a function of the width of the transmitter/receiver base. It might be enhanced when the detection was achieved on two consecutive bases. However, direction and altitude measurements "remain still a goal." In the case where an electromagnetic barrier was conjugated with a conventional method such as Krebs, it was only regarded as a complement thereto. The few advantages attributed to DEM concerned its level of automation and efficiency by night or on cloudy days.

When the tension seemed to release after Munich, a second Arsac report [23] brought some corrections to these restrictive views, saying, "The Electromagnetic method for aircraft detection should provide the Défense Antiaérienne du Territoire a new way of first order." This time, the benefits of low cost and mobility were especially emphasized. This second report concluded with recommendations for a complex system, combining three DEM lines staggered in depth to ensure the alert, the pre-contact, and the contact, in addition to an acoustic Krebs line, according a scheme experienced from June 1 to 30, 1938, at Châlons-sur-Marne (Figure 9).

5.3 Specific Developments for the Navy

During the same period, the Navy was engaged with its own needs in a self-development program, headed by M. Laville, scientific assistant at the Laboratoire du Centre d'Essais de Toulon. After the first successes in 1935, a barrier was planned to be set up between Cape Camarat (Saint Tropez) and Cap Martin (Menton), to warn of Italian air attacks on Toulon or Marseille. This program was well documented in the half-yearly reports of the Laboratoire du Centre d'Essais de Toulon [24]. It began with the study of new materials, a first step that was not without some friction between the two laboratories. The schedule of the

Figure 8. The double receiving station during an Arsac experiment at Condé, April 1938 [22].

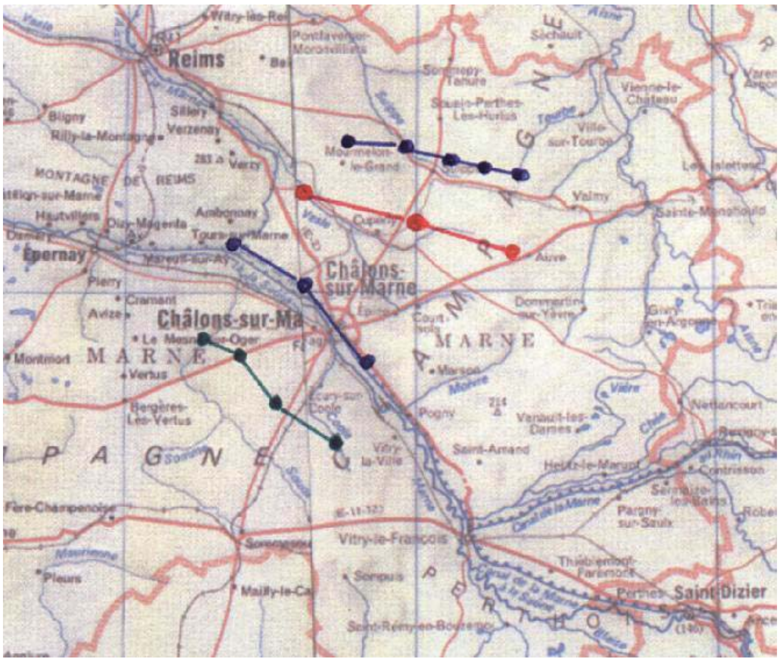


Figure 9. Triple DEM lines plus the Krebs line (in red), Châlons, June 1938.

trials themselves was impacted, delaying them until April 1936. However, after having increased the transmitter power up to 100 W, it was quickly confirmed that the specific propagation over sea provided very good detections, on bases of length from 50 km to 70 km, above a minimal altitude estimated at 400 m.

A definitive base was set up at Cap Ferrat for the transmitter and at Camarat for the receiver. It worked satisfactorily from September 1936 to April 1937 on a wavelength of 7.10 m. However, in a last test on May 26, the wavelength had to be set down to 5.75 m to take into account a summer change in the propagation. It would be seen later that this wavelength of 5.75 m was also usable in winter, and the Ferrat-Camarat equipment was finally tuned to this unique value, before being transferred to the Navy for its operational use.

(This question remained a subject of many discussions, the range of 5.5 m to 7 m normally being reserved for intercommunications between naval forces. Moreover, it was soon granted by the Cairo International Conference to TV transmissions. A note of March 30, 1938, again recommended the range 7.5 m to 10 m, and the next specifications would generally impose a wide tuning band, from 5 m to 10 m).

In June 1937, another provisional base was ordered from the Laboratoire du Centre d'Essais de Toulon, to be used in the Marseille area during the inter-army maneuvers scheduled for August. It was set up on July 27, still at 5.75 m, between Faraman and Croisette.

However, the maneuvers showed that these coastal locations did not give a sufficient warning time in case of air attacks against harbors or anchored naval forces. It seemed required to move one of the two elements of the base offshore, onto a ship or on a buoy. A trial with the transmitter set up on a destroyer was a failure, due to the reflections on the superstructure, and the modulation caused by the roll. However, in October 1937, testing a transmitter carried on a submarine was fully successful on a base of 50 km. The submarine proved to be a very safe station, even in very bad weather. A global project was established to cover the entire coast.

A coastal network shaped as a sawtooth was studied (Figure 10), with transmitters offshore placed as far away as possible, and receivers onshore. It still remained a feasibility study to pre-define the locations, but the barrier was to be quickly deployed in the event of war, with devices easy to carry and to use.

In 1937, the ambitious project to install a barrier between Corsica and the mainland proved too costly for then. However, first conclusive experiments were done in 1938, with a transmitter embedded on the sloop-ship *Les Eparges* at 200 km off Nice, and a receiver on a van at Fort de la Tête du Chien (La Turbie)

6. The Aborted Project of a Chain Home "*à la Française*"

After Munich, it was no longer time to field experiments or air maneuvers, but for concrete achievements. Concerning electromagnetic detection, the Air- Défense Antiaérienne du Territoire finally took two key decisions.

The first was to acquire the means to complete a chain of about 450 km long, all along the border between the Ardennes and Switzerland. A series of thirty new devices was ordered, each including one E-62 quartz-driven transmitter (60 MHz, 300 W), and two R-62 receivers with

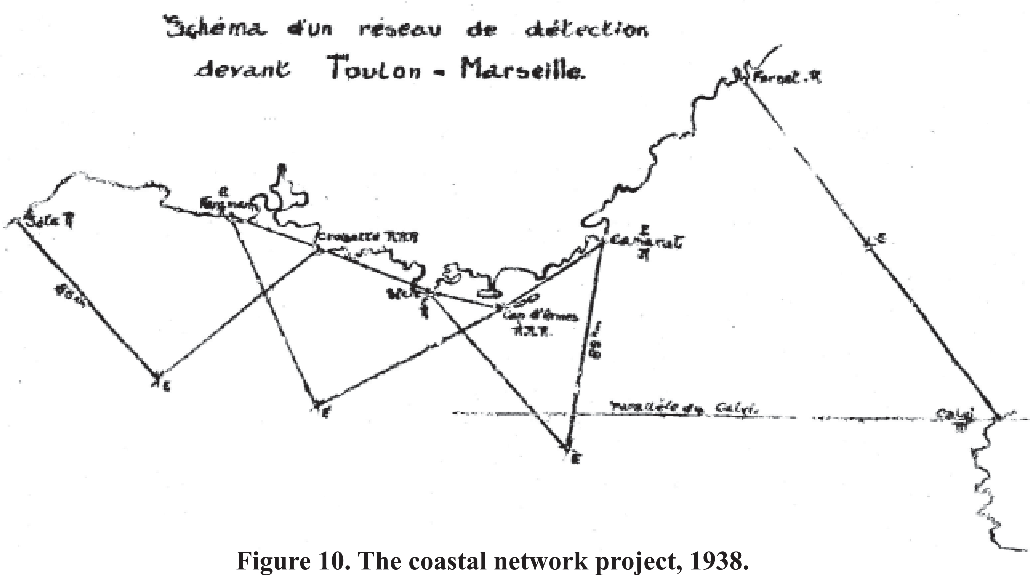


Figure 10. The coastal network project, 1938.

highly stabilized superheterodyne oscillators, alarm bells, and signal recorders. They were manufactured partly by the Etablissement Central du Matériel Radio at Issy les Moulineaux Fort, and partly by the private company La Construction Radioélectrique. They had to be delivered by spring 1939, and deployed along the borders as soon as possible.

The second decision was to create the 1st Company of Electro-Magnetic Watching, under the command of Captain Marc Contri. This would be responsible for deploying this equipment along the eastern border, in a continuous barrier operating during day and night.

However, the objective situation was not so clear! It soon appeared that this project of a Chain Home "*à la Française*" was by no means the result of any preliminary analysis, and no more the result of an implementation study, and that its architecture was absolutely improvised. Unlike the British chain, it seemed basically designed as a mobile system, which had to be deployed in a week, according to the tactical needs estimated at the moment by the Air-Défense Antiaérienne du Territoire Staff.

However, there was precisely no agreement at this level, where no fewer than three options were subject to harsh debates:

- A simple warning line, with positions spaced about 40 km on a 300 km front closest to the border. This would give only an alert (but infallible!), and a precise time of crossing the line, without direction or altitude, and even less, the number and type of aircraft.
- A line dedicated to fighter guidance, 60 km long with stations spaced at 10 km, between Laon and Hautvilliers, to stop air attacks that would have violated Luxembourg and would go to Paris.
- (As an emergency option, which became more pressing when the war situation deteriorated) moving this line around Paris.

In the same way, the creation of the company was nothing but the regularization of a situation that already pre-existed at the Centre d'Expériences Aériennes Militaires, where a team had been gradually constituted to ensure David's barriers tests. It was thus decided to set up the E-M Company from this first Electro-Magnetic Detection Section in Reims, with a staff reduced to 45 people, nine cars and... three bikes! Its basic mission was to insure the Centre d'Expériences Aériennes Militaires experiments, while providing training for the future managers of a maneuver unit that could be deployed in case of conflict. However, there was an advantage: it was prescribed that this detachment should not in any way be dispersed at the mobilization._

The height of the confusion came when some clear-sighted officers, aware of the imminent threat, advocated an urgent solution based on Anglo-French cooperation. Major Labat, head of the Section d'Etude des Matériels de Transmission, met Robert Watson-Watt on several occasions. Labat invited Watson-Watt to visit Labat's own laboratories at the Fort of Issy Les Moulineaux, where he was building up the equipment of David. Even if Watson-Watt was very skeptical at this time, the British position changed after March 1939, when they considered a possible extension of the Chain Home protection towards the German borders. They also had to ensure air coverage for the British Expeditionary Force, which would be concentrated in the region of Lille. In April 1939, a French mission, led by Lieutenant Ballande, was invited to visit British laboratories and test facilities. Ballande came back fully subdued: "The information that was given stunned us" [25]. On his return on April 19, he quickly established a project to meet the most urgent needs, with thirteen fixed-station type CH and nearly forty mobile station GL Mark I, for a total amount of 440 million F. The order was passed as soon as April 25. If we consider that during the previous years the bulk of the Défense Antiaérienne du Territoire annual funding was given to the purchase of sound-locating devices, and DEM was taken into account only as an extra, " provided it remained reasonably cheap!" it is clear that this order signed the death warrant of the French DEM.

The first stations were to be installed using British equipment and French-made infrastructure, energy supplies, and antennae. A few days after war was declared, Britain sent their specialists to draw up the plans for a chain of thirteen CH stations, which were to be supplied in September 1940. However, the war's circumstances dictated otherwise.

One can understand that the deployment of the 1st Company of Electro-Magnetic Detection remained discreet. In spring 1939, it had received the Etablissement Central du Matériel Radio materials, which had to be used to build the "French Electromagnetic Barrier" along the eastern border. Military archives have preserved some staffing tables, showing that the company included at the time about 200 soldiers and 10 officers. However, we know very little about their occupations during the first months of the so-called "phony war." According to Cazenave [18],

> the 1st Company of DEM set up a continuous barrage from the Belgian border to the Alpes, which worked remarkably in I939-1940, and fully met the expectations expressed in the early 1936. The number of failures was extremely limited, and virtually any group of aircraft or isolated aircraft crossing the barrier was detected.

However, nothing is known about the sites of implantation, probably modeled on the pre-existing air-watching lines of the Défense Antiaérienne du Territoire. One can especially ask where the alerts were transmitted, and how they were used.

Ironically, the equipment proved its advantage of mobility, especially during the debacle of June 1940. Clearly, the orders to retreat and to destroy stations given by General Vuillemin, Chief Commander of the Air Force, tried only to follow a situation that escaped him. One example was when Captain Contri was ordered on June 8, 1940, to set up a new barrier on the Swiss border [26]!

Paris was occupied on June 14, 1940, and the armistice, signed three days later, dismantled France into two parts. Contri and his company were lucky to have found themselves on the right side of the Demarcation Line, in the so-called Free Zone. Their journey ended at Cavaillon in Provence, where Contri was given the final order to deploy his equipment on the air-watching line "Y," north of Marseille.

The company, which still numbered about one hundred men, had saved eight E-62 transmitters and five double R-62 receivers from the debacle. They were deployed as

Figure 11. The last David's barrier at Valensole, 1940.

a last EM Barrier from Montperat (Gard) to Valensole (Vaucluse), with intermediate positions at St. Gervazy (Gard), Barbentane, Velorgues {Vaucluse), Apt (Vaucluse), and Reillanne (Basses-Alpes) [18, 27] (Figure 11).

The installations, which had not much more to hide, were inspected on March 24, 1941, by the 5th Joint Commission for Armistice Control, accompanied by two German engineers, who questioned the French operators mainly about English radars [28]. The EM Barrier remained authorized in so far as it was only a warning device, but should never be used for fighter guidance. This situation lasted at least until the invasion of the southern Free Zone by German troops on November 11, 1942.

6.1 The Navy EM Barriers

From the Navy side, things were more advanced when the war broke out. Unlike the Air Force, the Navy already had an operational network of EM Barriers on the Mediterranean coast, from the Camargue west to Ramatuelle east, covering all military or industrial areas around Marseille and Toulon. If we refer to the project of Figure 10, four onshore barriers were now in operation, and four with a transmitter offshore (with the exception of barrier No. 6) were ready for operation [29].

The devices were sheltered in wooden huts (Figure 12) giving the operators the best conditions to ensure the watch. Two types of materials from different origins were used:

Figure 12. A wooden hut for a Navy EM detection post, 1940.

- Laboratoire du Centre d'Essais de Toulon devices (transmitter 100 W, modulation 600 Hz, super-reactive receiver, bandwidth limited to the range 5.5 m to 5.8 m, detection by earphone only
- Thomson-SADIR devices (transmitter 50-75 W, modulation 600-800-1000 Hz, superheterodyne receiver), tunable in the range 7.5 m to 10 m, dual recorder Brion-Leroux.

Other methods were also explored. The Navy did not follow the Air Force politics of purchasing English radars, but chose to pursue its own research, using only the English experience as an inspirational source. By late 1938, a crash program was launched, calling on the participation of all French companies, large and small, operating in the field of radio engineering. They were asked to divert any equipment currently under manufacture for other purposes to the new DEM projects. The most significant achievement was made by LMT Laboratories, which diverted a powerful transmitter with completely unusual specifications for the time (30 kW at 46 MHz), intended for the Eiffel Tower TV station. It was made to work in a pulse regime ($P_p = 350$ kW at 48.5 MHz), to be used as an early warning radar, very much more ambitious than any other previous French project. It was installed in February 1940 on the island of Port-Cros, off Toulon [30].

Unfortunately, this equipment, which had been said to be "remarkable for its time," had a sadly short operational life: one week! It worked well after the declaration of war by Italy on June 10, 1940. During the night of June 12, it detected an attack by Italian planes over Toulon, giving an early warning at 120 km that led to 38 Italian planes being shot down. However, after France asked for armistice on June 17, 1940, the Navy decided to dismantle the station, which remained hidden on the island in separate elements.

On the other hand, the Navy Barriers of the 3rd Region, like the Air Barrier of Valensole, were maintained in operation, with the agreement of the 5th Joint Commission for Armistice Control, until the whole French fleet was scuttled to escape German capture in November 28, 1942.

On the Atlantic coast, David was asked to plan a full program of EM Barriers to protect the naval base of Brest. Six barriers were planned, according to Figure 13.

In August 1939, two barriers were operating (Ouessant (T): Pointe du Raz (R); Ouessant (T): Ile Vierge (R)). Three others were under construction (Ploumanach (T): Ile Vierge (R); Penmarc'h (T): Pointe du Raz (R); Penmarc'h (T): Belle-Île (R)) [31]. Transmitting and receiving devices worked in a wavelength range from 4 m to 10 m. They were made at the Brest Arsenal, for a total cost of 40,000 F.

All these barriers, operational or under construction, were destroyed at the arrival of German troops in Britanny on June 20, 1940.

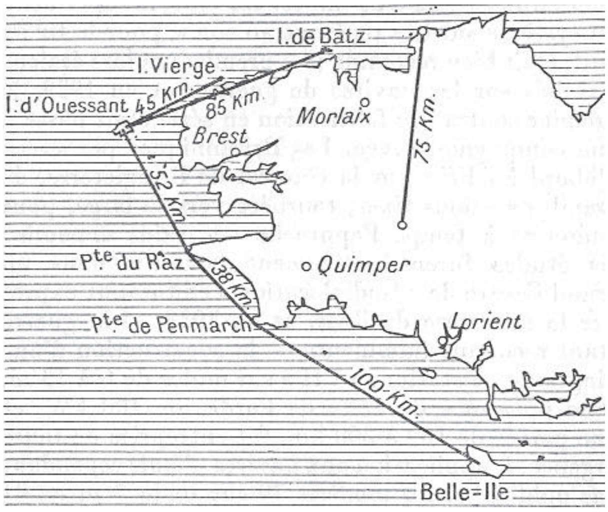


Figure 13. EM Barriers around Brest, 1940 [17].

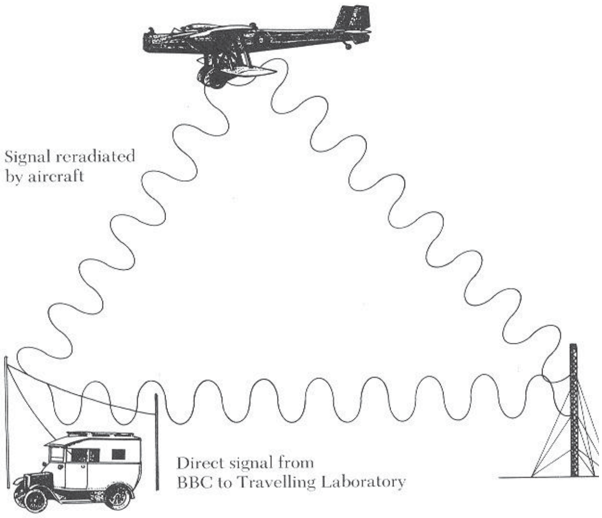


Figure 14. The Daventry experiment [34, p. 71].

7. Other Developments: Britain and Japan

In Great Britain, phenomena similar to the NRL observations were published on June 3, 1932, in a Post Office report [32], with an explicit chapter dealing with "interferences from Aeroplanes." However, no attempt was made to apply the beat method as a substitute to the giant acoustic mirrors, which were tested at this time before the Chain Home deployment.

In his autobiographical book [33], Sir Robert Watson-Watt, claiming for himself the title of "Father of Radar," refused to consider those interference methods – and the bistatic systems of Taylor or David, as well – as "true radar." It is thus a bit funny to note that he used the same principle when he hastily organized his famous Daventry experiment on February 26, 1935, to prove the feasibility of the radio-detection method that he had proposed in his memorandum dated February 14.

Under the supervision of the Tizard "Committee for the Scientific Survey of Air Defence," represented by its secretary, Arthur P. Rowe, Watson-Watt settled receiving equipment at $\lambda = 49$ m in a van parked in a field some kilometers from the Daventry BBC radio station. He asked a Heyford bomber to fly into the radio beam (Figure 14). The interference that appeared when the plane was at an estimated distance of about eight miles was significant enough to definitively convince A. P. Rowe that an aircraft would reflect enough energy to detect its presence [35]. As it is known, the following decisions were not long to come!

However, it was in Japan, during the first years of the war with China (1937-1945), that the *beat method* found its most significant operational application. At the beginning, Masatsugu Kobayashi, a TV engineer at NEC, followed the same path as his American, British, or French predecessors, but this time it resulted in a true military use. In May 1938, when making preliminary tests for the TV transmission of the Olympic Games that were to be held in Tokyo in 1940, he noticed blurring in his pictures, which was strongly correlated with aircraft takeoffs or landings at the nearby military airport of Tachikawa. The Olympic Games were cancelled after the outbreak of the conflict with China, but the observation was reported to Captain Kinji Satake at the Army's Scientific Research Laboratory. Satake found interest and funds to create a study group, including representatives from Tokyo Electric Company, JRC (Japan Radio Company), the Osaka and Tokyo Imperial Universities, and, of course, NEC, under the leadership of Kobayashi.

The team developed a system quite similar to David's Electromagnetic Barrier, in the 40 MHz to 60 MHz frequency range, with distances between transmitters and receivers of up to 100 km. As soon as it was engaged against China, the Japanese Army adopted this radio detector, designated as a Radio Locator Type A, or Bistatic Doppler Interference Detector (due to the sound generated by the beats, it was also known as the "*Bow Wow* type" or "*Wan Wan Shiki*"). It proved to be of value in China, detecting targets at more than 300 km distance [36]. It was said to have been built by NEC and Toshiba from 1941, in several hundred copies, in different versions.

8. The "Mailles en Z" (Z Lattices) Method, A Generalized Multi-Static Sensor System for Three-Dimensional Localization

As a matter of fact, it was pretty clear that the Electromagnetic Barriers had failed to fulfill the two functions for which they had been intended, although the reasons were not only technical. Faced with obsolete acoustic devices, they had not managed to create a decisive advantage as guidance systems for fighters in the dark night. More especially, the lack of a precise estimation of the altitude of planes made them unacceptable for antiaircraft fire control. In those pre-war times, this was mainly due to the ignorance of modern signal-processing tools (i.e., methods for solving inverse problems, and the maximum-likelihood estimator), which would today put the matter within the scope of a PhD student! At the Reims Centre d'Expériences Aériennes Militaires, the military operators, more often without real technical competence, could only wonder about the complex shapes appearing on their recorders when the situation was a bit complicated, as in Figure 15 with an over-flight of three aircraft. Unavoidably, there were some right-thinkers who said that "staying at lookout in the darkness of a tent facing an oscilloscope was not a military attitude!"

To extract the desired parameters, the operator could only rely on charts empirically established after a number of field experiments, with a rather doubtful reliability (Figure 16) !

To give a final answer to the question of altitude measurement, in 1937 David proposed an improved configuration by arranging transmitting and receiving stations on two parallel lines, separated by a few kilometers, according to a design he called "Mailles en Z" (Z lattices) [37] (Figure 17). A new credit of 60,000 F enabled him to build a pre-series of 12 new sets at the Fort d'Issy, designed to experiment with this new method. During the preparatory tests before the maneuvers of the summer of 1937, he obtained from the multiple combinations of transmitter-receiver lines a target-speed accuracy of close to 10%, the direction ±20°, and the altitude ±500 m.

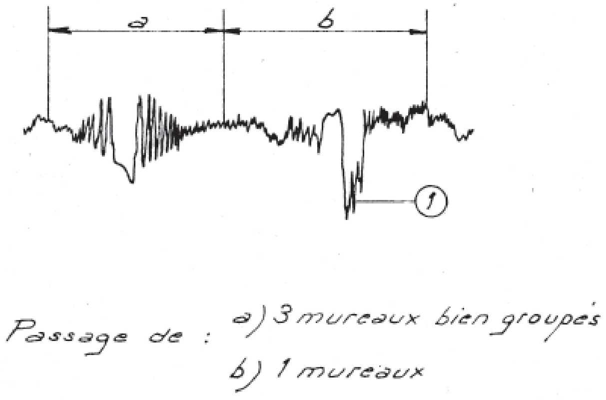


Figure 15. A recording of a passage of four planes, 1936 [22].

However, this method was considered too complicated to manage without any processing machine at that time. Cazenave, who attended the trials, acknowledged that the lack of interest shown by the Défense Antiaérienne du Territoire for the data coming from a single line was not stimulating to acceptance of an over-cost for its doubling, especially as hopes then focused on the adoption of the English RDF system. From October 1937 (as it was said above), David was left out of all new developments of Air Barriers. Despite the support of Major Labat, this new configuration – by all means the most innovative, as the first historical approach of a true multi-static system, and undoubtedly of real efficiency – was not experimented with in the following 1938 campaign.

9. Epilogue

When WWII started, certain things seemed understood: the pulse radar system prevailed everywhere. Watson-Watt "theorized" this restrictive point of view in the chapter "What is Radar" of his memoirs [32]. David himself endorsed this new trend when in October 1938 he concluded a memorandum to the Committee of Physics and Experiments with a strong recommendation to follow the new way of monostatic pulse systems [38]. During the war, apart from the Japanese "Wan Wan Siki," the most

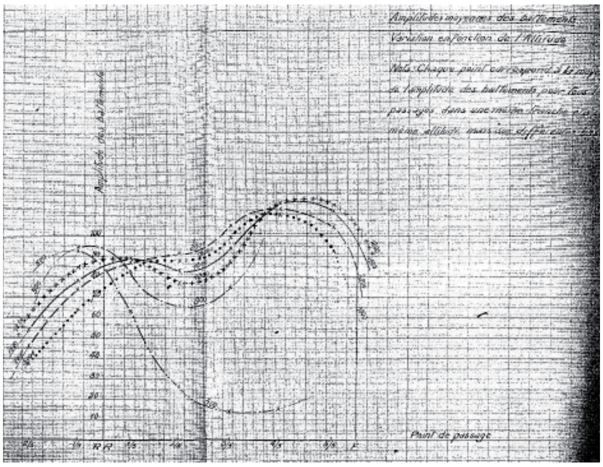


Figure 16a. Charts for the evaluation of flight parameters: the passing point [23].

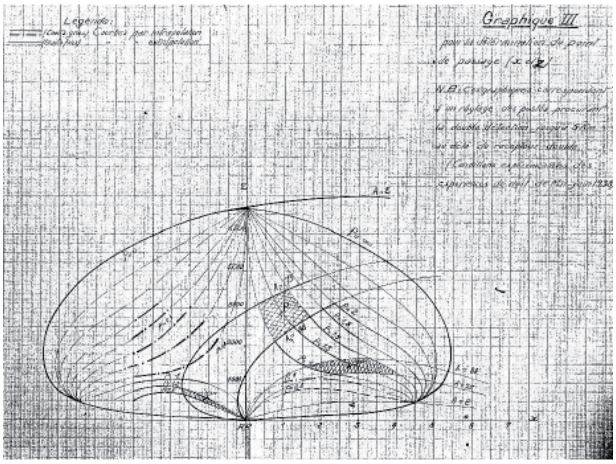


Figure 16b. Charts for the evaluation of flight parameters: altitude [23].

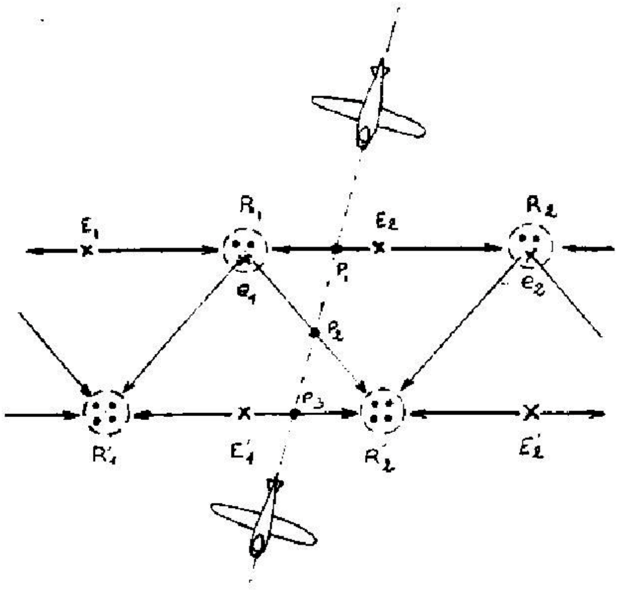


Figure 17. David barriers: the “Mailles en Z” configuration, June 1937 [37].

interesting innovation came from the German side. This was the imaginative “Klein Heidelberg,” which used as non-cooperative transmitters the English stations of the Chain Home, themselves [39]! After the advent of the magnetron in 1942, leading to the exclusive use of centimeter wavelengths, the architecture of “classical radar” seemed fixed for a long time. During two or three decades, progress could be summed up into “how to focus more and more peak power into shorter and shorter pulses and thinner and thinner beams.” This led to the giant air surveillance radars of the 1970s, impressive electromechanical monsters pushed to the latest technological limits, until they finally appeared as not totally free from any drawback: to avoid ambiguities when range and speed measurements had to be combined, for instance, or when a target pursuit needed increased beam agility.

This was the time when CW radars found new interest, and appeared as an alternative technique that was only dormant. The “bistatic radar” was introduced as a fully separate topic in the second edition (1990) of Skolnik’s *Radar Handbook* (Chapter 25, by N. J. Willis) [40]. However, according Willis, the name itself had been coined as early as 1952 by Siegel and Mahol [41]. The subject was updated in 2007 by Willis and Griffiths [42]. Many examples were quoted in these books. We can add in France the new “HF Fences” developed by LCTAR in the 1980s, and the bistatic GRAVES by ONERA for satellite tracking [43]. However, at that time the matter did not stop at a simple CW line between two points. It benefited from the advent of distributed or sparse array theory, of which the French RIAS [44], and its Chinese copy [45], were two early precursors.

Today, all these systems are gathered under the banner of “MIMO (multi-input multi-output) radars” [47] (Figure 18), which covers an infinite variety of multi-static configurations. The modern theories of space-time signal processing, and the capabilities of digital computers – the two elements that David lacked for his “Mailles en Z” – have opened the way to free the imagination of a new generation of radar designers.

10. Acknowledgments

The author would like to thank his friends, M. H. Carpentier and J. M. Colin, for their encouragement and advice during this work. Special thanks are due to P. F. Aujas for sharing his invaluable documentation on the subject.

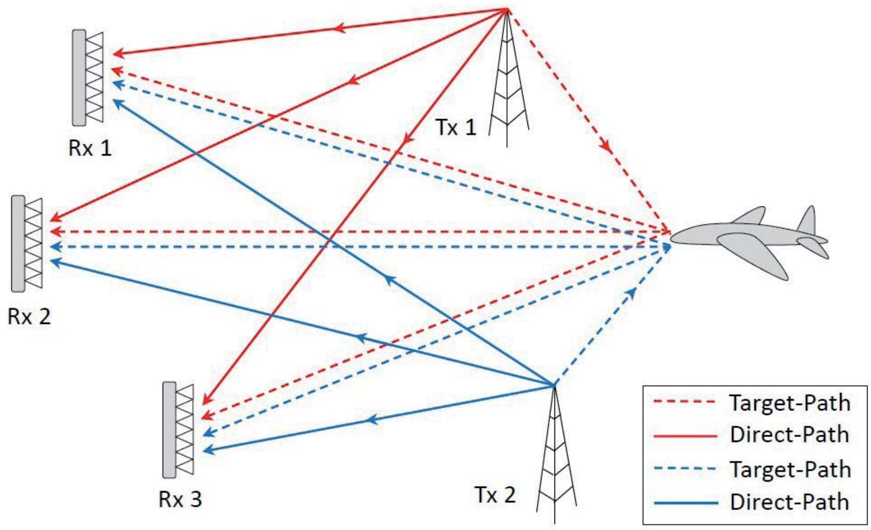


Figure 18. An example of a modern MIMO radar (from Himed [46]).

11. References

1. G. Galati, *100 Years of Radar*, Berlin, Springer International Publishing AG, 2015.

2. R. C. Watson, Jr., *Radar Origins Worldwide*, Bloomington, Trafford Publishing, 2009.

3. Y. Blanchard, *Le Radar, 1904/2004: Histoire d'un Siècle d'Innovations Techniques et Opérationnelles* [The Radar, 1904/2004: One Century of Technical and Operational Innovations], Paris, Ellipses ed., 2004 (in French).

4. Y. Blanchard, "The Origins and Development of Radar: An Account of the French Contribution," in *100 Years of Radar*, DGON (Deutsche Gesellschaft für Ortung und Navigation), 2005, pp. 91-120.

5. H. E. Guerlac, *Radar in WW II*, New York, Thomas Publishers, 1987, pp. 211-213.

6. Y. Blanchard, "Maurice Ponte and Henri Gutton, Pioneers of Early French Studies on Resonant Magnetron, 1932-1940," Proceedings of IET International Cavity Magnetron Conference (CAVMAG 2010), Bournemouth, April 19-20, 2010, pp. 5-10.

7. Y. Blanchard, G. Galati, and P. van Genderen, "The Cavity Magnetron: Not Just a British Invention," *IEEE Antennas and Propagation Magazine*, **55**, 5, October 2013.

8. R. Mesny, "Les Ondes Très Courtes " [The Very Short Waves], *L'Onde Electrique*, **2**, 25, January 1924, pp. 25-37; **2**, 26, February 1924, pp. 99-110.

9. Capitaine Jund, Lieutenant-Colonel Laure, and P. David, *Procès-Verbal des Essais d'Ecoutes de Bruits Rayonnés au Palivestre* [Minutes of Listening Tests of Radiated Noise at Palivestre], Commission d'Expériences de Bourges, April 15, 1930.

10. P. David, "Historique de la Détection Electromagnétique" [History of Electromagnetic Detection], typed report, 1938, with a handwritten note by David: "copy of a 1938 report destroyed in 1940 as all the mentioned references."

11. P. David, "Memorandum on Aircraft Detection," pli SOLEAU n°4944N, French Industrial Property, May 5, 1930; "Opening Minute of n°4944N," May 1935.

12. General Challéat, "Letter to General Commander of French Signal Corps," n°340 S/E, February 20, 1939.

13. R. M. Page, *The Origin of Radar*, New York, Anchor Books, Doubleday and Co, 1962.

14. A. H. Taylor, L. C. Young, and L. A. Hyland, "System for Detecting Objects by Radio," US Patent No. 1981884, filed June 13, 1933.

15. C. R. Englund, A. B. Crawford, and W. M. Mumford, "Some Results of a Study of Ultra-Short-Wave Transmission Phenomena, Field Fluctuations from Moving Bodies," *Proceedings IRE*, **21**, March 1933, pp. 475-493.

16. P. Revirieux, "Paul Labat et la Détection Electromagnétique" [P. Labat and the Electromagnetic Detection], *La Liaison des Transmissions*, n° 59, September-October 1969, pp. 10-13.

17. Pierre David, *Le Radar*, coll. Que Sais-Je ?, Paris, PUF ed., 1969.

18. Colonel Cazenave, "La Détection Electromagnétique en France avant le Radar" [Electromagnetic Detection in France before Radar], *Bulletin de Liaison de l'Amicale des Transmissions de l'Armée de l'Air*, February 1970, pp. 18-19.

19. Pierre David, Letter to Pierre Cazenave, April 20, 1968, Cazenave's personal archives.

20. General Duchêne, "Détection des Avions en Vol" [Flying Planes Detection], correspondence to Air Ministry, n° 5.791/S, March 28, 1936, SHAT (archives of French Army Historical Service), Vincennes.

21. CEAM, Centre d'Expériences Aériennes Militaires [Center for Military Aerial Experiments], " Rapports Secrets sur les Expérimentations de Chasse de Nuit, 1936-1938 " [Secret Report on Night Fighting Tests, 1936-1938], file 7 N 3946, SHAT (Archives of French Army Historical Service), Vincennes.

22. Capitaine Arsac, "Résultats Obtenus avec les Matériels de Détection Electromagnétique à la date du 5 juillet 1938" [Review of Electromagnetic Detection Results on July 5, 1938], CEAM report n° 1057/S, July 29, 1938, SHAT (Archives of French Army Historical Service), Vincennes.

23. Capitaine Arsac, "Valeur du procédé électromagnétique de détection des avions: précision, délais d'utilisation, application à la manœuvre de chasse" [Value of planes Electromagnetic Detection, precision, reactivity, application to fighter guidance], CEAM report n° 1376/S, 10th October 1938, SHAT (archives of French Army Historical Service), Vincennes.

24. LCET, "Comptes-rendus semestriels" [Half-year reports], Centre d'Etudes de Toulon, nos 82 (August 1, 1936) to 88 (August 1, 1938).

25. H. Ballande, *De l'Amirauté à Bikini*, Paris, Presses de la Cité, 1972 (the copy we used was widely commented by margin notes handwritten by Col. Cazenave).

26. Général Vuillemin, "Organisation d'un Barrage de DEM. sur la Frontière Suisse" [Setting up a E-M Barrier on the Swiss border], letter n° 706bis/I.G.D.Aé/3/S, to the Signal Commander of DAT, June 8, 1940).

27. Colonel Sezestre, "La Compagnie de DEM, 1940-1944," typed note to Col. Cazenave, 1969, Cazenave's personal archives.

28. Contre-Amiral Aubin, "Activité de la Commission n°5, Détection Electro-Magnétique," [5th Commission Activities, E-M Detection], letter n° 721 EM ARM, to Navy's Chief Admiral, April 9, 1941.

29. Contre-Amiral Michelier, “Situation de la DEM en 3ème Région au 15 Octobre 1939, [Situation of E-M Detection in 3th Region at October 15, 1939], letter n° 578 EMG Trans, to Maritime Prefecture of Toulon (October 20, 1939).

30. Ernest Giboin, “L’évolution de la Détection Electromagnétique dans la Marine Nationale ” [An history of the E-M Detection in the French Navy], *L’Onde Electrique* n°287, February 1951, pp. 53-64.

31. Contre-Amiral Tavera, “Etablissement de barrages électromagnétiques en 2ème et 5ème Région” [Setting up E-M barriers in 2nd and 5th Regions], note n° 1467 E.M.G.1 “Secret” aux Préfets maritimes des 2ème et 5ème Régions maritimes (August 4, 1939).

32. Nancarrow, Mumford, Carter, and Mitchell, “The Further Development of Transmitting and Receiving Apparatus, Part V: Interference from Aeroplanes,” British Post Office Radio Report n° 233, London, June 3, 1932.

33. Sir R. Watson-Watt, *Three Steps to Victory, A Personal Account by Radar’s Greatest Pioneer*, London, Odhams Press, 1957.

34. B. Johnson, *The Secret War,* London (BBC ed.), 1978, p. 71.

35. A. P. Rowe, *One Story of Radar*, Cambridge, Cambridge University Press, 1948, p. 8.

36. Y. Nakagawa, *Japanese Radar and Related Weapons of World War II*, Laguna Hills, CA, Aegean Park Press, 1997, pp. 15-16.

37. P. David, “Quelques Commentaires sur l’Histoire du Radar” [Some Comments about the Radar Story], *La Liaison des Transmissions*, n°75 (May-June 1972), pp. 15-20.

38. P. David, “Note au Comité d’Etudes et d’Expériences Physiques” [Note to CEEP, Committee for Studies and Physical Experiments], October 1938.

39. H. Griffiths, “Klein Heidelberg, the First Modern Bistatic Radar System,” *IEEE Transactions on AES*, **46**, 4, October 2010, pp. 1571-1588.

40. N. J. Willis, “Bistatic Radar,” in M. L. Skolnik (ed.), *Radar Handbook, Second Edition*, New York, McGraw-Hill, 1990, Chapter 25.

41. K. M. Siegel, “Bistatic Radars and Forward Scattering,” Proceedings of the National Conference on Aeronautical Electronics, May 12-14, 1958, pp. 286-290.

42. N. J. Willis and H. D. Griffiths, *Advances in Bistatic Radar*, Raleigh, NC, SciTech Publishing, 2007.

43. T. Michal, J. Bouchard, and J.-P. Eglizeaud, “GRAVES: The New French System for Space Surveillance,” Proceedings of the 4th European Conference on Space Debris (ESA SP-587), Darmstadt, April 18-20, 2005, p. 61.

44. J. Dorey, Y. Blanchard, and F. Christophe, “Le Projet RIAS, une Approche Nouvelle du Radar de Surveillance Aérienne” [RIAS Project, a New Approach of Air Surveillance Radars], L’Onde Electrique, 64, 4, July-August 1984, pp.15-20.

45. C. Baixiao, Z. Shouhong, W. Yajun, and W. Jun, “Analysis and Experimental Results on Sparse-Array Synthetic Impulse and Aperture Radar,” Proceedings of IEEE International Radar Conference RADAR 2001, Beijing, 2001, pp. 76-80.

46. B. Himed, D. E. Hack, and L. K. Patton, “Direct Cartesian Localization in Passive MIMO Radar Networks,” Proceedings of IEEE International Radar Conference RADAR 2014, Lille, October 13-17, 2014, WEO.2.5.

47. Eli Brookner, “MIMO Radar Demystified,” *Microwave Journal*, **56**, 1, January 2013, pp. 22-44.

Introducing the Author

Yves Blanchard was born in 1942. He is a consulting engineer. He graduated from ISEN Lille in 1966. He has been a research engineer in sonar and radar for 25 years. He was first with the French National Centre for Aerospace Studies & Research (ONERA), where he worked as project manager on innovative radars such as the HF radar “RIAS” and the OTHR “Nostradamus.” He then joined industry at Thomson-CSF (now Thales), as Research Director at Thomson Sintra Underwater Activities, and at Thomson-CSF Missile Electronics. He ended his career as Technical Director of the Missile Electronic unit of Thales Airborne Systems.

He is also a well-known researcher into the history of radar, and has given nearly 40 papers and conferences on the subject. He is the author of a general history of radar developments, acknowledged in France as a reference book: *Le Radar 1904-2004, Histoire d’un Siècle d’Innovations Techniques et Opérationnelles* (Ellipses ed., Paris, 2004). He is currently working on the French radar story before WWII, and on the German radars used in occupied France during the war. He is Chair of the Association for the Development of the German-French Museum of Radar at Douvres la Delivrande, Normandy.

Glimpses of Early Radar Developments in Ukraine and the Former Soviet Union

Felix J. Yanovsky

National Aviation University
Prospekt Komarova 1, 03058 Kiev, Ukraine
Tel: +380 44 4067370
E-mail: yanovsky@nau.edu.ua

Abstract

The first experimental work on practical radar detection in the USSR was done in 1934, to detect an airplane in flight as a target for flak or antiaircraft artillery. This work was absolutely independent of radar research and development in other countries. The outline of the first work on radar development in the USSR is briefly described in this paper on the basis of generalizations of documents, articles, and books published earlier (mostly in Russian). The attention in this paper will also be focused on the original radar research and development in Ukraine, which was then a part of the USSR. The first three-coordinate radar system was developed in 1938 in Kharkiv, the capital of Soviet Ukraine in the 1919-1934 period. Earlier, in the 1920s, the first powerful UHF and microwave oscillators were also created in Kharkiv, including magnetrons, which served as key engineering components of the future radar systems. Later, many important achievements were made in Ukraine, such as wideband signal generation, and pulse compression using a matched filter, in the middle of the 1950s. Radar development in modern Ukraine was based on its powerful scientific schools and industry.

1. Introduction

Modern radar can be defined as the science and technology encompassing the methods and means of detection, coordinate measurement, recognition, and determination of the motion parameters and other characteristics of observed objects using reflection, re-radiation, or emission of electromagnetic waves. The possibility of detecting objects using electromagnetic waves was expressed at the beginning of the twentieth century, but was prepared by earlier work.

It is worth mentioning James Maxwell's brilliant theory; the works by Heinrich Hertz, who tested and experimentally proved key results of Maxwell's theory; experiments on wireless communications in the Baltic Sea by Alexander S. Popov, who noted in his report that radio communication established between two ships was subject to the interference due to reflection from a third ship when it passed between them; foresight articles and lectures by Nikola Tesla; and Guglielmo Marconi's wireless devices. Many other achievements can be considered as forerunners of radar. However, the first working device that directly implemented the basic principle of active monostatic radar was built by Christian Huelsmeyer, to detect river boats at a distance. It was patented in 1904 in Germany, and named Telemobiloskop. Huelsmeyer's invention had no commercial success then, and it was pretty quickly forgotten. He was ahead of his time.

The creation of modern radar was gradually prepared by the general level of science and technology, and the needs of society. Only in the thirties of the twentieth century did the technical and economic, as well as the social and military conditions, appear and coincide for the development of practical radar. That is why it is not too strange that almost in parallel and independently, purposeful research on the creation of radar devices was started at least in France, Germany, Great Britain, Hungary, Italy, Japan, the Netherlands, the Soviet Union (the USSR), and USA. Normally, Sir R. A. Watson-Watt is pointed to as one of the key founders of the first real radar technology. In July 1935, together with his colleagues, he successfully demonstrated a radar for detecting an aircraft, and for estimating its coordinates. After improvements, a radar network (Chain Home) based on this system was built to provide early detection of enemy aircraft.

The activities in the field of radar performed in the USSR were published later than in other countries. They were less accessible to Western historians of science, and were often not considered by them. In this work, more attention is therefore paid to the history of radar in the former Soviet Union and Ukraine, without intending to claim stronger advances and priority. In reality, these works can be considered to be quite fundamental and, in certain aspects, pioneering. They were done in isolation and without publicity, caused by the pre-war circumstances and the general Soviet "spy-mania." All the investigations in this field were heavily classified as Top Secret.

Up to the 1930s, for air defense, acoustic direction finders together with optical range finders were used to determine the aircraft's location. They were able to quite accurately determine the direction-of-arrival of the sound emitted by the aircraft's engine. Such a system was called "prozhzvuk," which is actually an abbreviation of two words in Russian: "searchlight" and "sound." Such a system could be used only with a cloudless sky. Even then, it had negligible efficiency, as the pilot, once into the spotlight, could dramatically change the course and make the result of the calculating unit unusable for the control of anti-aircraft fire. With increased flight speeds and aircraft altitudes, the direction of sound arrival and the direction to the airplane began to differ so much that the "prozhzvuk" system became generally incapacitated. The need to create a fundamentally new means for the detection of aircraft became apparent.

The idea of testing the possibility of using radio methods to detect aircraft originated from military engineers. The advantages of radio were obvious: the high speed of propagation, the ability to work during the day and night, in the clouds, and behind the clouds, regardless of the weather. However, nobody had any idea how to approach this task, nor who could carry out the entire set of necessary research and development. Of course, in addition they had no idea how difficult this task would be. One of the main initiators was Mikhail M. Lobanov (1901-1984), later a Lieutenant General (Figure 1), and another was Pavel K. Oshchepkov (1908-1992) (Figure 2), later Doctor of Technical Sciences (but a Gulag prisoner for 10 years, beginning in 1937). Both were then young, talented, and very active professionals. At the end of their lives, both of them published their memories [1, 2], which contained lots of interesting facts and details.

Figure 1. M. M. Lobanov (circa 1975).

Figure 2. P. K. Oshchepkov (circa 1935).

Being a field synthesized of science and technology, radar has incorporated advances in the theory and technology of antennas, radiowave propagation, transmitters and receivers, signal processing, automatic control, information display, etc. It is impossible to pay appropriate attention to all these issues in a single paper. This paper summarizes the information known to the author from the literature, as well as from personal communication with some of direct participants in the hard and long process of radar development. In particular, the author was lucky to have a long period of communication with Profs. Yakov S. Itskhoki (1906-1984), Yakov D. Shirman (1919-2010), Yakov S. Shifrin, and Moisey I. Finkelshtein (1922-1992). He even met and in 1975 spoke to Yuriy B. Kobzarev (1905-1992). In the same year, 1975, the book by M. M. Lobanov [2], entitled *Beginning of Soviet Radar*, was published (in Russian). In spite of the obvious influence of "Soviet patriotism," this book contains a lot of important facts and documents, a part of which is cited in this article. In addition, we have archival material and interviews with participants in the events that were collected and saved by their younger counterparts.

Following the advice of Prof. Yakov Shifrin, who today is the oldest scientist in Ukraine who contributed to radar, in [3] we divided the process of radar development into five stages: 1) The very first works (1920-1941); 2) the period of WW II since the occupation of Ukraine (1941-1945); 3) the postwar period (1945-1955); 4) the period of intensive radar development (1955-1990); 5) modern radar (1991 to present). In this article, the period of the first two stages is mainly considered in detail, that is, since 1920 to the middle of the 1940s. A couple of later achievements (around 1955) are briefly described.

Table 1. A list of the abbreviated names of the institutions in this paper.

ARTA	Artillery Radio-Technical Academy (in Kharkiv, Ukraine); later name: VIRTA: Voennaya Inzhenernaya RadioTechnicheskaya Akademiya (Military Engineering Radio-Technical Academy)
CRL	Central Radio Laboratory
DC	Department of Communications
GAU	Glavnoe Artilleriyskoe Upravlenie (Principal Department of Artillery: PDA in English)
IRE	Institute of Radio Physics and Electronics NASU (National Academy of Sciences of Ukraine)
KA	Krasnaya Armiya (RA in English)
KhSU	Kharkiv State University
LEMO	Laboratory of ElectroMagnetic Oscillations
LEPI	Leningrad Electro Physics Institute
LETI	Leningrad Electro-Technical Institute
LIPT	Leningrad Institute of Physics and Technology
NII-9	Nauchno-Issledovatelskiy Institut No9 (Research and Development Institute #9: RDI-9)
NIIIS	Nauchno-Issledovatelskiy Ispytatelniy Institut Svyazi (RDTIC in English)
PCD	People's Commissariat of Defense (the name of Ministry of Defense of the USSR in 30s)
PDA	Principal Department of Artillery (GAU in Russian)
RA	Red Army (KA in Russian)
RDI-9	Research and Development Institute #9 (NII-9 in Russian)
RDI Radio-Industry	Research and Development Institute of Radio-Industry
RDTIC	Research, Development, and Testing Institute of Communications (NIIIS in Russian)
UIPT	Ukrainian Institute of Physics and Technology

Today, almost 80 years later, we have the possibility of compiling and generalizing the memoirs, papers, interviews, and recorded conversations to recreate an eye-opening picture of the research, development, and implementation of the first radar facilities in the USSR, also taking into account that this picture was painted in the harshest years of the twentieth century.

Figure 3. Yu. K. Korovin, a pioneer of radar in the USSR, developer of a CW radar.

2. First Experiments on Radio Detection of Airplanes

2.1. Radio Detection in UHF Band

Mikhail Lobanov, a military engineer, served in the Glavnoe Artilleriyskoe Upravlenie – GAU (Principal Department of Artillery – PDA) of the People's Commissariat of Defense (PCD), actually the Ministry of Defense, since 1932 (see Table 1 for a list of abbreviations of the names of institutions that appear in this paper). He was one of the initiators and organizers of the first research and development on radio detection for anti-aircraft artillery. In his memoirs [2], Lobanov told the following story. The idea to use radio waves for detecting airplanes (particularly bombers) was expressed in the PDA, but military engineers did not know who would be able to fulfill the necessary research. In 1933, during a private talk, Lobanov asked B. N. Mozhzhevelov, the Department Head of the Central Radio Laboratory (CRL), how he would have reacted to the idea of radio detection of aircraft. This question arose because the PDA intended to propose that the CRL conduct research in this direction. Mozhzhevelov recommended speaking first to Yu. K. Korovin, and then perhaps to officially apply to the Director of the CRL. At that time, Yuri K. Korovin (1907-1988) was the leader of the Decimeter Waves Group in the CLR, and was busy with two-way communications at decimeter wavelengths. His group had already developed transmitters, receivers, and measurement devices to conduct

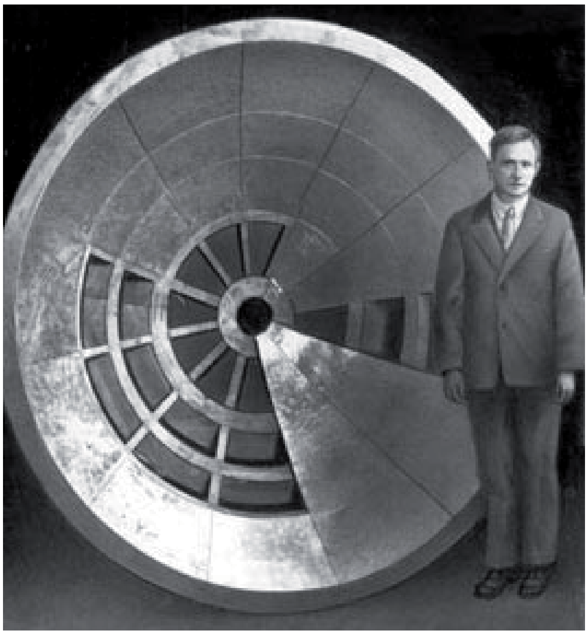


Figure 4. The original antenna designed for the first radar experiment. V. A. Tropillo is standing next to the antenna.

testing of communication range. D. N. Rumyantsev, the Director of the CRL, immediately agreed, and in October 1933, a contract was signed [4]. It was a legal document – the first in the USSR – that started research and development work as well as financing in the field of radar. Yuri Korovin (Figure 3) was assigned as leader of this work. Two-way radio equipment was allocated to carry out the experiments. This equipment was made earlier (except for the antenna) in the CRL, and used by Korovin in his investigations of the task of the Department of Communications (DC) of the Red Army (RA). The equipment contained:

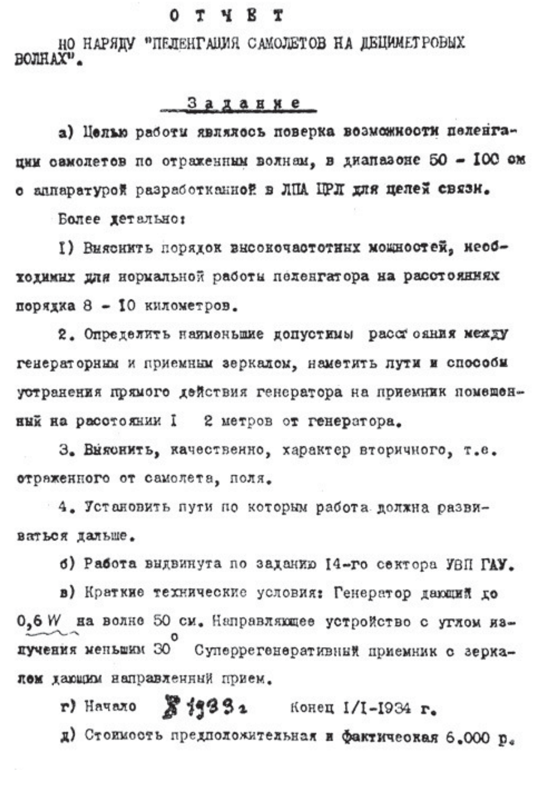
- A continuous-wave transmitter operating at a wavelength of 50 cm to 60 cm, but of very low radiating power: 0.2 W;
- A super-regenerative receiver;
- And two ground-based parabolic-reflector antennas of 2 m diameter (Figure 4).

Figure 5. Yu. A. Katsman.

Oscillating tubes for this equipment were developed in 1932-1933 by engineers of the Leningrad Electro-Technical Institute (LETI) V. I. Kalinin and Yuri A. Katsman (Figure 5), together with CRL researcher V. A. Tropillo (see Figure 4). A 1 m^2 screen of sheet brass initially served as a reflective surface to adjust the transmitter and receiver. A brash mesh of 10 m^2 was later substituted for it.

The main experiment to verify the radiowave reflections from flying aircraft was organized in Leningrad. Tests were carried out on the area of the rowing port. Radiating equipment was placed on the shore, and the receiving equipment was on sea ice at 20 m from the shore. The transmitting and receiving antennas were similar. According to the agreement with the PDA, experiments on the radio detection of the airplane were planned in December 1933. However, due to adverse weather conditions with a lack of ice thickness off the coast of the Gulf of Finland, the experiment was postponed.

Finally, on January 3, 1934, the weather improved, and the long-awaited experiment of radio detection of aircraft was carried out. During the experiment, a seaplane made several takeoffs and landings with different angles relative to the direction of radiation and reception. The reception apparatus allowed observing the Doppler effect in the form of a typical sound in the headphones when the seaplane entered into the zone of visibility.



ОТЧЕТ

НО НАРЯДУ "ПЕЛЕНГАЦИЯ САМОЛЕТОВ НА ДЕЦИМЕТРОВЫХ ВОЛНАХ".

Задание

а) Целью работы являлось поверка возможности пеленгации самолетов по отраженным волнам, в диапазоне 50 - 100 см с аппаратурой разработканной в ЛПА ЦРЛ для целей связи.

Более детально:

1) Выяснить порядок высокочастотных мощностей, необходимых для нормальной работы пеленгатора на расстояниях порядка 8 - 10 километров.

2. Определить наименьшие допустимы расстояния между генераторным и приемным зеркалом, наметить пути и способы устранения прямого действия генератора на приемник помещенный на расстоянии 1 2 метров от генератора.

3. Выяснить, качественно, характер вторичного, т.е. отраженного от самолета, поля.

4. Установить пути по которым работа должна развиваться дальше.

б) Работа выдвинута по заданию 14-го сектора УВП ГАУ.

в) Краткие технические условия: Генератор дающий до 0,6 W на волне 50 см. Направляющее устройство с углом излучения меньшим 30° Суперрегенеративный приемник с зеркалом дающим направленный прием.

г) Начало VIII 1933 г. Конец 1/I-1934 г.

д) Стоимость предположительная и фактическая 6.000 р.

Figure 6. The report from CRL to PDA on the first experiment on radio detection of aircraft (first leaf). The start of the work was in August 1933, and the work ended January 1, 1934. The price was 6000 rubles.

The seaplane was detected at a distance of 600 m to 700 m at 100 m to 150 m flight altitudes. Judging by these figures, it was quite a short distance, but in essence it established the key fact of detection of the reflected signal from an aircraft. In 1935, Yu. K. Korovin got the "Author Certificate" (a kind of patent) number 2578, "Device for Radio-Detection of Aircraft Based on Using Doppler Phenomenon."

During the next several days of January, Yu. Korovin held a number of flight tests, and collected reliable enough material for further work on the development of new equipment for detecting aircraft and direction finding. In the CRL report, sent to PDA by February 14, 1934 (Figure 6), Yu. Korovin formulated the first results of his work:

1. The direction finding of aircraft was possible at a distance of 8 km to 10 km in the case of a radiating power of the order of tens of watts and a wavelength of 10 cm to 20 cm. This conclusion was based on the results obtained with a power of 0.2 W at a wavelength of 50 cm.

2. At 0.2 W power and a wavelength of 50 cm, the aircraft was detected at a distance of 600 m to 700 m.

3. Direction finding of elementary surfaces (a 25 cm diameter disc) was obtained at the same power and the same wavelength at a distance of 100 m. The experiments with elementary surfaces allowed roughly calculating the reflection effect from complex reflectors (aircraft).

4. Obtaining secondary characteristics of the field, that is, the distribution of the reflected field in space depending on the position of an aircraft in the irradiated zone, was possible at a transmitter power of the order of 4 W to 5 W at a distance of 1 km to 1.5 km. The apparatus used (0.2 W) did not allow the experimenters to carry out these measurements.

5. Use of a multilayer screen made it possible to reduce the distance between the transmitting and receiving antennas to 1 m to 2 m; at a wavelength of 50 cm and a power of 0.2 W, the shortest distance between those antennas was 8 m.

Later, Yuri Kobzarev (1905-1992), a pioneer of pulse radar, wrote in his memoirs [5]:

> January 3, 1934 in Leningrad, the radio waves reflected off the aircraft were registered using a small purpose-built device. From that day, which can be regarded as the birthday of the Soviet radar, the intensive research began.

The conclusions of the PDA in 1934 were also very optimistic. They reviewed and approved the CRL report [6]. In addition, the need was identified to boost development of radio-detection equipment, both in the CRL and in the Leningrad Electro Physics Institute (LEPI), to initiate a parallel development. The decision of the PDA provided for the desirability of speeding up the work to manufacture and test the operational prototype of the device during the same 1934.

2.2. Radio Detection in VHF Band

As was mentioned above, engineer Pavel Oshchepkov, who in 1932 served in the army, also proposed a similar idea for radio detecting aircraft. He intended to improve the air defense of the Red Army. The structure of the Air Defense Service included a series of observation posts, which were equipped with just binoculars and telephone communications to alert the Air Defense Command Points. In the Department of Air Defense, the idea of radio detection thus emerged based on the analysis of the organization of air-defense surveillance at observation posts.

The difference between the approaches to radio detection in two Red Army departments (PDA and Air Defense) might not seem too obvious. However, it was. The purpose of the PDA was application of radio-engineering methods to detect aircraft for better aiming the antiaircraft artillery, while in the Air Defense, the purpose was to alert as early as possible regarding approaching bombers.

In the second half of 1933, in his report to the People's Commissar of Defense, Pavel Oshchepkov outlined the principle of using the new means of radio detection of aircraft in the air-defense system. More detail was described in [7]. The request for assistance in the promotion of activities on radio detection of airplanes by Pavel Oshchepkov, as a representative of the Air Defense Department, was directed to academician Karpinsky, the President of the Academy of Science, who asked Abram F. Ioffe (1880-1960) for assistance. Ioffe did not work directly as a radar developer or designer, but his role was very significant.

2.3 A Short Biography of A. F. Ioffe

Abram Ioffe was born in 1880 in the town of Romny, situated in the province of Poltava (the central part of modern Ukraine). He was from a merchant family. He received higher education in the Romny specialized school from 1889-1897. His schoolmate and close friend was Stepan (Stephen) Timoshenko, the father of modern engineering mechanics. Ioffe graduated from St. Petersburg Institute of Technology. He got a PhD from Munich University, where his teacher was Wilhelm Konrad Roentgen. Ioffe then rejected the flattering offer to continue working with Roentgen, and returned to St. Petersburg. (At the end of his life, when Roentgen was seriously ill, Ioffe gave him money for X-rays and treatment).

Ioffe was a wonderful physicist in the Russian Empire and in the Soviet Union. In 1911, he determined the charge of the electron. His article was published only in 1913, a little bit later than was done by Robert Milliken, who is officially recognized as the first. Ioffe was extremely effective as an organizer of science, and was a creator of the powerful scientific school in the Soviet Union. In 1916, Ioffe organized his famous Seminar in Physics for young scientists in St. Petersburg. The participants in that seminar later became the pride of Soviet physics. He was a teacher of A. P. Alexandrov, P. L. Kapitsa, N. N. Semyonov, L. A. Artsimovich, I. K. Kikoin, Ya. I. Frenkel, I. V. Kurchatov, and many other prominent scientists.

After the October revolution of 1917, Ioffe worked on the development of science under the new conditions. He was a very influential person, and the greatest authority in physics and engineering. He was also a smart and experienced "politician," which gave him the possibility of avoiding expressing a political preference for a long time, and being useful for science and for scientists under the difficult conditions of the Soviet reality. It was even strange that, according to [54], he became a Communist Party member only in 1942, in wartime, when he was 62.

Abram Ioffe was officially Vice President of the Academy of Science (never President), but he was known as the "Principal" Academician, father of Soviet Physics, or just "papa Ioffe." In 1918, he organized the Physics and Mechanics faculty in the Polytechnic institute where engineer-physicists were prepared. In the same year, 1918, he created and headed the Physics and Engineering Department at the State Roentgenological and Radiological Institute. In 1921, this department was transformed into the entire institute of applied physics, named the Institute of Physics and Technology (IPT), later the Leningrad IPT (LIPT) of the Academy of Sciences, and A. Ioffe became the Director of the LIPT. Today, this institute in St. Petersburg is named after Abram Ioffe.

A huge number of research works done in LIPT were not signed by Ioffe, in spite of his significant contributions: Ioffe was notable for his generosity in science, and did altruistically help his pupils. It was Ioffe who asked Rutherford, the head of Cavendish Laboratory in Cambridge, to invite Piotr Kapitsa for work placement. In addition to LIPT, Ioffe headed the Agrophysics Institute since 1932. He was the initiator and very actively participated in the creation of the institutes for Physics and Technology in Kharkiv, Dnipropetrovsk, Sverdlovsk, and Tomsk. He could have been the leader of the Soviet atomic project, but he was brave enough to refuse this offer in favor of a younger scientist: Igor Kurchatov. Stalin said, "I don't know such academician," but Ioffe insisted, and Kurchatov was appointed and awarded with the title of Academician.

In the beginning of the 1950s, when the anti-Semitic campaign on the "fight against cosmopolitism" was developed in the USSR, Ioffe was fired by the institute created by him. Nevertheless, he did not capitulate: he organized a new Laboratory of Semiconductors. After Stalin's death, he became the Director of the institute created on the basis of that laboratory. Ioffe was posthumously awarded the Lenin Prize (the highest award in the post-Stalin USSR) in 1961.

However, let us go back to radar history. Abram Ioffe always quickly responded to any fresh idea [5]. Very soon, he thus invited his friend, Dmitry Rozhansky (1882-1936), as well as Alexander Chernyshov (1882-1940), Nikolay Papaleksi (1880-1947), Boris Shembel (1900-1987), Pavel Oshchepkov, et al., to the meeting organized by him on February 7, 1934. After the meeting and positive discussions, the Red Army Air Defense Department signed a contract on February 19, 1934, with LEPI [8] to study the reflection of electromagnetic waves from different surfaces, to develop radio-detection equipment, and to conduct the first experiments to detect aircraft. Based on the accumulated material, it was then planned to develop a draft of an air-reconnaissance station. Engineer Boris Shembel was appointed as the immediate supervisor of the research. It is interesting to note that B. Shembel had already started to work on radio detection according to the contract with the PDA.

Before June 1, 1934, the equipment named "Rapid" was developed. This consisted of an electromagnetic wave oscillator (4.7 m wavelength, 200 W power), a superheterodyne receiver, and a receiving antenna designed as a horizontal dipole. In June, "Rapid" was tested near Leningrad. The radiating system was installed on the roof of LEPI and oriented into the direction of the receiver; it was stable during the tests. The receiver was moved within 11 km to 50 km from the radiating system. An airplane, following its planned course, crossed the track of the electromagnetic radiation (the so-called "electromagnetic veil") at different points of the line-of-sight between the radiating and receiving equipment to determine the maximum distance at which the receiver still could reliably detect the airplane.

According to the test results of July 10-11, 1934, a record was compiled where it was indicated that the airplane was detected in all cases when it was within 3 km from the receiver at altitudes up to 1000 m. On August 9 and 10, 1934, experiments with "Rapid" were repeated. The reception apparatus was installed in the Krasnogvardeisk area (50.4 km from the transmitter), and in the Siverska station (70.6 km from the transmitter); the airplane flew at altitudes up to 5200 m. In these experiments, the beat signal from the aircraft was heard with headphones at distances of 5 km to 7 km from the receiver.

In September 1934, the LEPI presented the second release of the "Rapid" equipment: a 100 W transmitter operating at a wavelength of 4.8 m, with the antenna system radiating at 60° in azimuth and elevation, and the receiver at the central station where a recording unit registered the received signals on a tape.

The "Rapid" device served as one of the prototypes for further development of radio-detection systems at NIIIS of the Red Army and in the radio-factory industry. At this point, the Red Army Air Defense Department stopped the work with LEPI, even though it had not yet been fully completed in accordance with the terms of the contract. The reasons were not fully clear, but very soon after, the LEPI was liquidated (more details are in the next section).

3. Continuous-Wave or Pulsed Radar?

In a note dated January 4, 1934, Pavel Oschepkov wrote his principal considerations about the viability of a pulsed method of radio detection instead of the continuous-wave method. His idea was based on the fact that in order to increase the detection range, the output power should be significantly increased. In the continuous-wave method, the manufacturing of high-power oscillating tubes caused considerable difficulties, due to the prolonged heating of the electrodes. Powerful VHF tubes at that time required water cooling, and had a service life of only 50 hours. Use of these tubes was impractical, even in a half-load mode. Oshchepkov supposed that when using pulsed radiation instead of CW, the main difficulty in the production of high-power VHF oscillating tubes – that is, the high temperatures on their electrodes – would disappear. According to his calculations, the power per pulse could be 100,000 times greater than the average power for continuous radiation, and this increased the range of detection. Today it is obvious that his conclusion was wrong: in reality, in order to detect a target at great distance, one needs significant mean power in the sounding waveform for both the CW and pulse methods.

In making his calculations, Pavel Oshchepkov arrived at the idea of creating a station with 360° visibility, determining two coordinates of the target: azimuth and range. However, this idea was not used in terms of research and development at that time. The systems with 360° visibility were developed and produced in radio factories ordered by the PDA a few years later. They were used for observation and alerting in the Air Defense Service, and as systems guiding flak artillery.

Although Oshchepkov expressed the idea of a preference for the pulse method, it thus did not result in the expression of a corresponding task of the LEPI. The development was carried out on the basis of the continuous-wave method, and recording of the Doppler frequency.

Shortly after the meeting at Abram Ioffe's office (February 7, 1934), Alexander Chernyshev applied to the Military Invention Division of PCD with the first application (in the Soviet Union) for an invention in the field of radio detection: "Device for the Detection of Airplanes and Airships in Flight by Means of Electromagnetic Waves." Its essence was as follows: the radio-detection system would consist of a single continuous source of powerful electromagnetic radiation, and a large number of radio receivers located on the periphery around it. When a non-directional radiation transmitter was used, the power should be significant; in case of directed radiation, it could be much less. In the latter case, a directional antenna rotated and sequentially illuminated the horizon, or a part of it. Some experts, such as Prof. Boris Vvedensky (1893-1969), expressed serious comments on this approach, mainly because of problems caused by continuous radiation. It was noted that the use of pulsed radiation could save on average power and facilitate the fight against unwanted interference from the "direct" signal.

In accordance with the contract [8], the following performance characteristics were intended to be reached:

- Detection of aircraft in the observed area and coordinate determination at altitudes up to 10 km and at a distance of 50 km;
- Range accuracy of 2% to 5%;
- Determination of the number of airplanes (one, two, unit, troop, squadron, and more);
- Accuracy of determining the aircraft's speed up to 25 km/h.

Such LEPI obligations under the contract with the Air Defense Department demonstrated that neither LEPI nor the customer had yet imagined the complexity and scope of research and development necessary to provide such requirements.

As was mentioned above, although further experiments carried out in March 1935 with the improved equipment showed that the detection range could be significantly increased, LEPI's work in this direction was terminated by the customer. By this time, inside the Air Defense Department, the Experimental sector was created, with laboratories in Moscow and Leningrad. The orders for the development of a powerful VHF generator of continuous radiation and appropriate reception facilities were given to industry for the planned early warning system "Elektrovizor," also proposed by Oshchepkov.

In 1935, the LEPI was disbanded. Its premises, personnel, and equipment were handed over to the NII-9, or Research and Development Institute #9 (RDI-9). This was a new institute, which was organized for the development of important defense topics, including radar. Mikhail A. Bonch-Bruevich (1888-1940) was appointed as the scientific director of the new institute. He was known as the founder and leader of the former famous Nizhny Novgorod Radio Laboratory. Bonch-Bruevich knew very well the work of radio operators: "listeners" of the first World War. He believed that the most promising method was the acoustic indication of the received signals. Indeed, the ability of wireless operators to extract the necessary signals from the incredible cacophony of sounds (a mixture of signals of many stations, caused by bad selectivity of the receivers) was amazing. A strong preference for the continuous-radiation technique was therefore given in RDI-9. Actually, the work was aimed at creating radio-direction finders to replace the old acoustic system, which was combined with optical projectors (the so called "Projector-Sound"). Especially attractive (from their point of view) was a resemblance of these systems, so that operators would not even have to relearn [5].

There were many difficulties during the development of continuous-wave systems. They mostly occurred due to the proximity of the CW transmitter to the receiver, even if they were spaced apart by tens of meters. In 1934, in parallel with the work of the Boris Shembel team in LEPI, the pulse radio-detection method was also tested. The research on pulse radar was led by engineer Moisey D. Gurevich. Under his leadership, the experimental setup was based on a UHF magnetron oscillator working in pulsed mode. The oscilloscope, synchronized by the generator, was connected to the output of the receiver. The direct and reflected pulses could be simultaneously marked on the screen. However, this work was also stopped [2]. The management had continued to give priority to the CW method, especially since there had been significant advances in the creation of the transmitting and receiving UHF devices. Only after 1938, at the Leningrad Institute of Physics and Technology (LIPT), when the experiments had been conducted that demonstrated the high performance of pulse technology, did the pulsed radar method get the rights of development also in RDI-9. However, the "Projector-Sound ideology" was not completely overcome: the pulse method was viewed only as a means of allowing replacement of the optical rangefinder by a radio-rangefinder (to allow the operation of the plant under cloudy conditions). Development of a decimeter direction finder with continuous radiation continued to play a leading role in the RDI-9 institute [5].

Anyhow, at that time, a radar system with continuous radiation that could be adopted for operational use was not created. All attempts to build a CW operational prototype failed [9].

At the same time, considerable success had been achieved in the application of the pulse method in the Ukrainian Institute of Physics and Technology (UIPT). There, in 1938, a pulsed-radar system was created for anti-aircraft artillery (it was called the "Zenit"). This system operated in the 60 cm to 65 cm wavelength range [2, 10]. More details about this apparatus are in Section 5.

4. First Radars for Anti-Aircraft Artillery

In 1935-36, the RDI-9 had to create a new mobile apparatus for radio detection for anti-aircraft artillery, and thoroughly test it on the range. Based on the experimental setup of 1935, and its testing using an airplane and a simulator, the pilot plant of the RDI-9 produced a transportable two-antenna flak radio searcher, "Burya." The name radio searcher (radioiskatel) was used for this kind of radar. This development was still carried out in the laboratory headed by Boris Shembel. The radio searcher "Burya" included:

Figure 7. The radio-searcher "Burya."

- A magnetron oscillator at a wavelength of 24 cm to 25 cm, with a power of 6 W to 7 W continuous wave;
- A regenerative receiver and detector with direct amplification;
- Two parabolic antennas (radiating and receiving) with diameters of 2 m and beamwidths of 7° to 10°;
- A power supply (batteries and dry cells).

To facilitate the development of the radio searcher, the PDA gave to the RDI-9 a regular (acoustic) rangefinder, ST-2. The horns and acoustic transmission lines were removed, and parabolic antennas were installed at the attachment points. All the radio equipment, together with batteries, were placed on the frame and the rotating base of the ST-2 sound ranger.

During the thorough testing, the "Burya" radio searcher (Figure 7) showed a target detection range (maximum) of 10 km to 11 km, with a median error in azimuth of 3° and in elevation of 4.1°.

The performance of the radio searcher surpassed similar characteristics of the acoustic rangefinder. However, the "Burya" radio searcher did not yet fully satisfy the requirements of the anti-aircraft artillery.

During the field tests in Crimea, Boris Shembel first noticed and then systematically observed the reflection of electromagnetic waves from distant mountains (about 100 km). This indicated that radio waves of 24 cm to 25 cm

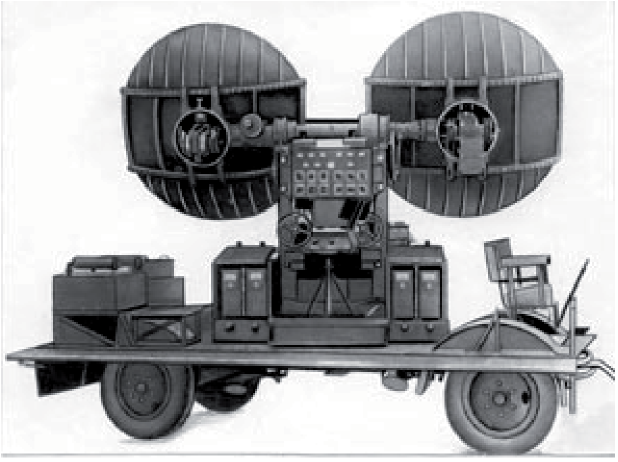


Figure 8. The radio-searcher B-2.

could be used for aircraft detection at distances much greater than those obtained at the site. This fact was very important for future developments. During observations of reflections from the mountains, the method of frequency modulation (FM) of the magnetron was used, which was introduced by Boris Shembel into the "Burya" equipment. Based on this experience, the idea of range measurement with FMCW radar was proposed by Shembel in 1937 [9].

The new radio searcher B-2 (Figure 8) had a parabolic antenna with a squinted antenna pattern and a beamwidth of 5° to 6°. To search for the aircraft, it used a conical scan within the sector of 40° to 50° in azimuth and elevation. By successively irradiating the airspace sector by sector, the radio searcher detected the airplane, and then switched to tracking by determining the angular coordinates by the equi-signal-zone method.

For further development of radio searchers, Mikhail Bonch-Bruevich suggested using the idea of a flat antenna beam, that is, a fan-shaped radiation pattern. He emphasized that flat antenna patterns were able to simultaneously solve two main tasks: to increase the reliability of detection and searching for aircraft, and to improve the accuracy of determining the coordinates. Therefore, the next system that implemented this idea was the B-3 system. Two B-3 radio searchers formed a complex, in which one unit (azimuth) was designed to search for targets in the horizontal plane, and the other unit (elevation angle) searched in the vertical plane (Figure 9). Together, they determined the target's coordinates in space-angle. Both radio searchers had antennas with flat antenna patterns (fan-shaped), with a beamwidth of 35° to 40° in one plane, and 2° to 3° in the other plane.

Both radio searchers were of identical structure and electronics, but they only differed in appearance by the fact that the antenna of the azimuth unit was horizontal, and the elevation-angle unit's antenna was vertical. The coordinates of the target were determined by the maximum audibility of the reflected signal. Later on, preference was given to a pulse radar for anti-aircraft artillery.

5. Three-Dimensional Pulse Radar Development in UIPT

Ukraine was one of the most technically advanced republics in the USSR. It formally had legal attributes of independency, such as its own constitution and the formal right to secession – which, of course, was impossible to implement, in practice. Before the collapse of the USSR in 1991, Ukrainian scientists were involved in the overall development of science and technology of the USSR. Considering the contribution to radar, one should note that the most powerful community of radio-physicists in Ukraine was in Kharkiv. The history of radar in Ukraine (and in the USSR, as well) is inseparable from the history of the creation of the community of radio-physicists in Kharkiv in the twenties of the twentieth century. That is why we shall first briefly recall the essential milestones that are relevant to radar [11-13, 53].

5.1 Kharkiv Radiophysics School

By the beginning of the twentieth century, Kharkiv was a large industrial, cultural, and scientific center, with lasting university traditions. The Kharkiv State University (KhSU) was established by imperial decree in 1804. Remarkably, KhSU had four departments, including a Department of Physical and Mathematical Sciences. During the first hundred years after its opening, the university trained a galaxy of prominent scientists, whose works brought them worldwide fame: mathematicians S. N. Bernshtein, M. V. Ostrogradsky, A. M. Lyapunov, and V. A. Steklov; biologist I. I. Mechnikov; chemist N. N. Beketov. physicists A. I. Akhiyezer, L. D. Landau, I. M. Lifshits, and K. D. Sinelnikov; chemist D. I. Mendeleev; and astronomers M. P. Barabashov and V. G. Fesenkov lectured at KhSU. The

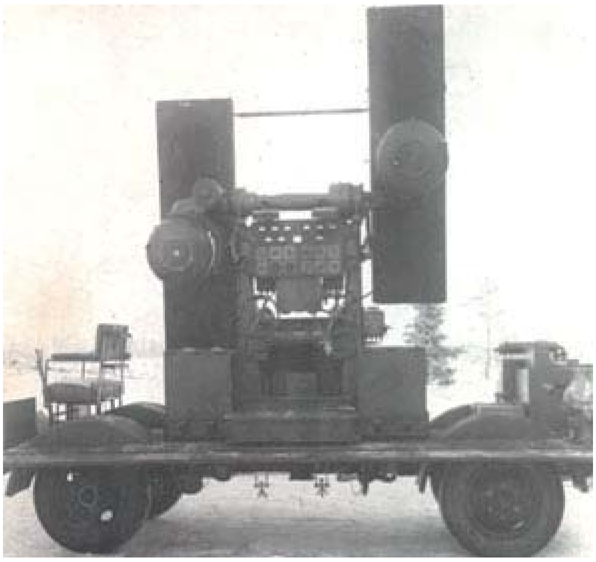


Figure 9. The radio-searcher B-3: the device for determining the elevation angle.

Figure 10. D. Rozhansky (1882-1936).

Figure 11. A. Slutskin (1891-1950).

university won a reputation as one of the most prestigious schools of higher education in the Russian Empire, and became a center of advanced science and technology. After the October revolution and bloody civil war, Kharkiv was chosen as the capital city of the Soviet Ukraine from 1919 to 1934 (at that time, Kiev was considered less politically reliable). One of the first research departments of physics in Ukraine was established in the KhSU in 1921. It was a new, independent scientific unit [12].

The department was established under the leadership of the prominent physicist, Dmitry Rozhansky [13]. Dmitry A. Rozhansky was born in Kiev, studied at the Kiev High School (the First Gymnasium), where famous writers Mikhail Bulgakov and Konstantin Paustovsky also studied, as well as the prominent aircraft designer, Igor Sikorsky. Rozhansky graduated (with an honors diploma) from the St. Petersburg University in 1904, and spent two semesters (1905/1906) in the laboratory of Prof. H. Simon in Gottingen, Germany, where he published his papers in the *Physikalische Zeitschrifft* journal. He finally defended his MS dissertation in 1908. Dmitry then worked in the Physics Department of the St. Petersburg Institute of Electrical Engineering under the leadership of Alexander S. Popov. Rozhansky moved back to Ukraine (to Kharkiv) in 1911, and in 1914, he became a Professor and Head of the Department of Physics at the KhSU. The Kharkiv period was very fruitful for Rozhansky's creativity. In 1913-1914, several of his fundamental results were achieved. In particular, in the book *Electric Rays*, he presented the physical foundations of radio engineering at the highest scientific level. At the same time, his famous book *Electric Oscillations and Waves* was published in two parts. As a recognized scientific leader, he had grouped around himself similarly minded associates, creating a supportive atmosphere and determining the topics of research.

Rozhansky was one of the first who foresaw the future of high-frequency radio engineering, and he initiated research on electromagnetic oscillations. In fact, this gave birth to the Kharkiv radiophysics community as a whole.

Research by D. A. Rozhansky (Figure 10) led to the creation of UHF magnetrons in Kharkiv [14] by his pupil, Abram A. Slutskin (Figure 11), together with Dmitry S. Shteinberg (1874-1934), who also was a follower of Rozhansky, despite his age (Figure 12). According to the reference of the great radio physicist, academician Leonid Mandelstam, these works were the most valuable in the field of electronics of that time [15]. The use of magnetrons in radar led to a revolution in this field.

In 1921, Rozhansky was invited to the famous Nizhny Novgorod Radio-Engineering Laboratory. However, in 1923, he moved to Leningrad (then Petrograd, today St.

Figure 12. D. Shteinberg (1874-1934).

Figure 13. A group of UIPT people during the visit of P. Ehrenfest to Kharkiv in 1930.

Petersburg) where, together with L. I. Mandelstam and N. D. Papaleksi, he took part in the organization and worked at CRL.

After leaving Kharkiv, Rozhansky kept in close contact with his former staff and students. He visited Kharkiv twice a year [15]. Around 1924, Abram Ioffe invited Rozhansky to the Leningrad State Physics-Technical Laboratory, organized by him, and to the Physics-Mechanical Faculty of the Leningrad Polytechnic Institute, where Rozhansky led the Department of Technical Electronics.

Rozhanky was interested in issues of short-wave propagation, and in 1925 he again came to Kharkiv. There in Kharkiv, he met Yu. B. Kobzarev who, still being a student of Kharkiv University, assisted Rozhansky during measurements of receiving signals. Later, D. Rozhansky invited the talented student to Leningrad.

Rozhansky was an honest and deeply principled man, who never did anything that could be against his conscience, and he never was afraid to express his opinion. This was not easy in the environment of increasing suspicions, spying-mania, and the approaching mass repression of the 1930s in the USSR. In the country, the fight against "enemies" was intensified that time. In Leningrad, a group of "saboteurs" was charged with mass poisoning at one of the factories, and 40 people were shot without court trials. In all institutions, meetings were organized where people usually voted unanimously, expressing the collective approval of the execution over "enemies." At such a meeting, on September 25, 1930, Rozhansky took the floor and said that he was an opponent of executions, especially without a court trial [16]. This action obviously served as a pretext to arrest Rozhansky on the night of October 4-5, 1930. Abram Ioffe immediately began to plead for his release. However, Ioffe only achieved that Rozhansky was released in nine months. Fortunately, after the prison stay, Rozhansky continued his scientific and pedagogical activity during several more years. However, his health was undermined, and he died in 1936, at the age of 48.

Prof. Rozhansky always stimulated the interest of young scientists, and promoted many of them, who later became famous. It was no accident that two of his students, Abram Slutskin in Kharkiv and Yuri Kobzarev in Leningrad (who also graduated from Kharkiv University), headed the work on the development of the first Soviet pulsed-radar systems.

Here, we have come to the principal hero of the story about the first three-coordinate pulsed radar. There is no doubt that Abram Slutskin (1891-1950) was the most remarkable man in Ukrainian radiophysics and electronics between 1925 and 1950 [11]. He played a crucial role in developing modern radio science. A. Slutskin entered the Physics-Mathematics Department of KhSU in 1910, just before Rozhansky's arrival. Rozhansky started a very interesting physical seminar, with active student participation. This determined Slutskin's ever-lasting interest in electronics. Slutskin graduated from the university in 1916. He worked there as an assistant until 1928, and then as a professor in the Physics Department. In 1928, for three weeks he worked in the laboratory of Barkhausen in Gottingen, Germany. Thanks to his brilliant results in physics and microwave electronics, he was awarded the degree of DSc in 1937, without defending a thesis. He was elected a Corresponding Member (1939) and later Academician (1948) of the Academy of Sciences of Ukraine. His work was focused on the magnetron and on pulsed radar.

An important event in the development of the Kharkiv radiophysics community occurred in 1928, when a new research and development center named UIPT was founded. The key role in organizing this institute was played by A. Ioffe, who was then the Director of the LIPT. He persuaded the government that a certain decentralization of Soviet science was necessary, and suggested that Kharkiv was the best choice for a new institution. A. Slutskin and D. Shteinberg (1874-1934) were included among the UIPT staff, still keeping their university posts. A group of UIPT people is shown in Figure 13.

Figure 14. A. Y. Usikov.

Systematically, the scientific level of UIPT became very high. Since 1932, Lev Landau (1908-1968), the future Nobel prize winner, was assigned Head of the Theoretical Department at UIPT. Landau was only 24, but he was already a world celebrity in theoretical physics. In addition, he lectured at Kharkiv Technical University (Polytechnic Institute) [17]. In the summer of 1934, the International Conference on Theoretical Physics was held in Kharkiv. Niels Bohr and other prominent theoreticians took part in that event. At that time, such famous scientists as Paul Dirac, Paul Ehrenfest, Vladimir Fock, George Gamow, Piotr Kapitsa, George Placzek, Rudolf Peierls, and Victor Weisskopf quite often visited UIPT, and some of them stayed there for a long time.

However, we can definitely assert that Landau had no relationship to the work in the field of radar. He was greatly interested in theoretical physics, and did not work on engineering problems, especially related to military issues. In contrast, Slutskin was a physicist who was greatly interested in engineering. He foresaw major trends, especially in microwave electronics and related fields of physics. In the first half of the 1920s, he investigated vacuum tubes in a magnetic field, and got magnetron oscillations. In 1924, he had gotten L-band oscillations, and continued to work hard to conquest even higher frequencies. Actually, the development of three-dimensional pulse radar at L band (see the next subsection) in UIPT was mainly associated with his intuition and initiative, because there was no obvious reason for this choice of frequency band and exactly the pulse method. Research and development in the field of higher-frequency bands later became the scientific credo of his followers. In particular, this was true relative to Alexander Usikov (1904-1995) (Figure 14), one of the founders (1955) and the first Director of the IRE (the Institute of Radio Physics and Electronics) in Kharkiv, whose activities were focused on the development of millimeter and sub-millimeter bands. The laboratory of electromagnetic oscillations (LEMO) was created as a division of UIPT as early as in 1930, and, of course, it was led by A. Slutskin.

5.2 Creation of Effective Microwave Magnetrons in Kharkiv

Effective microwave oscillators – in particular, magnetrons – later became the key components of radar systems. UIPT was one of the first institutions where the development of effective magnetrons was done. A. Slutskin began to work on this even much earlier. In 1924, after his success in getting L-band oscillations in generators of the magnetron type – that is, reaching the most high-frequency part of the spectrum then available – he began to work hard to achieve even higher frequency bands. Slutskin investigated the mechanisms and conditions of excitation of split magnetrons, and developed a theory of a magnetron oscillator operating in the dynatron mode. According to Usikov [33], Slutskin enjoyed an extremely high reputation as initiator of a completely new method of oscillation: the split-anode magnetron. Another active member of that team, Semion Braude (1911-2003),who was only 22-25 (Figure 15) when working on magnetrons, noted [15]:

> Slutskin was my teacher, as he lectured on electrodynamics in KhSU where I studied. It was with his personal support that I was assigned to UIPT after my graduation. I have been formed as a scientist under a strong influence of him....It should be noted that he personally supervised all the research projects of his staff, and every day discussed the results obtained.

An interesting analysis of the first publications on magnetrons was written in [18]. According to [18], the first publication on magnetron oscillation was by A. W. Hull, whose papers [19, 20] appeared in 1921. Soon, A. Zachek

Figure 15. S. Y. Braude.

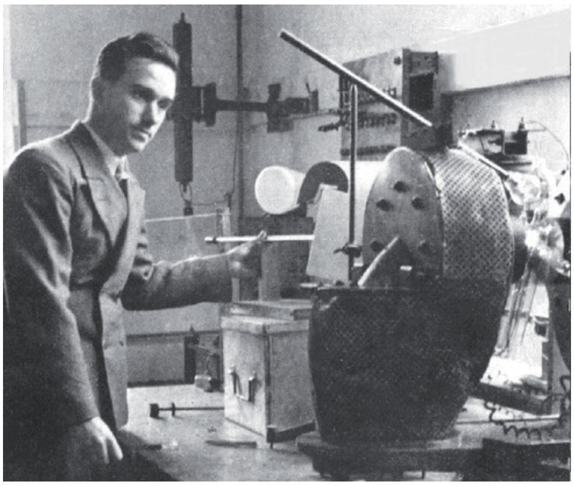


Figure 16. I. Truten.

demonstrated (in 1924) the possibility of generating high-frequency oscillations by connecting an oscillation circuit between the magnetron's cathode and its anode, and applying a permanent magnetic field of a strength close to its critical value [21]. E. Habann revealed (in 1924) that by splitting the anode into two equal segments (a split anode), between which a high-frequency circuit was placed, the output power could be drastically increased [22]. In the same 1924 at KhSU, A. Slutskin and D. Shteinberg [18] investigated the processes occurring in electron tubes under the impact of an external field. By using the three-electrode tube, they succeeded in generating electromagnetic oscillations within the wavelength band of 40 cm to 300 cm [23]. Later, they studied the effects associated with the tube-element geometry, operation modes, and the magnetic-field strength [24]. At their request, industry manufactured diodes where the anode was made from a nonmagnetic material (tantalum) [11, 18]. By the end of 1925, these studies enabled A. Slutskin and D. Shteinberg to obtain oscillations with a wavelength of 7.3 cm. This was mentioned in the memorial paper about Slutskin [25], written by his former student Ivan Truten (1909-1990), whose picture is shown in Figure 16. Additionally, this result was stated in a book [26] with a reference to the archive materials [27]. Here, one should keep in mind that important pioneering experimental work was also published in 1928-1929 by H. Yagi [28] and K. Okabe [29], with a magnetron having a split anode in the form of two half-cylinders. It is obvious that all the works mentioned were really independently performed. From this analysis, one can conclude that there is no doubt that – together with the other researchers better known in the West – A. Slutskin and D. Shteinberg can be considered to be pioneers of the magnetron-oscillation method.

Later, many different magnetron oscillators were developed in LEMO-UIPT. In Figure 17, a magnetron with a hollow anode, water-cooled from the inside, is shown. Two half anodes were connected by tunable circuits, consisting of metal tubes for bringing in the water and carrying it away. This design, proposed by Lelyakov, later served as the basis for different modifications. Braude, Lelyakov, and Truten had developed a water-cooled magnetron in a glass case, which enabled them to achieve an output power of 5 kW to7 kW at a wavelength of 80 cm. Even higher power (up to 17 kW in the CW mode) with 55% efficiency

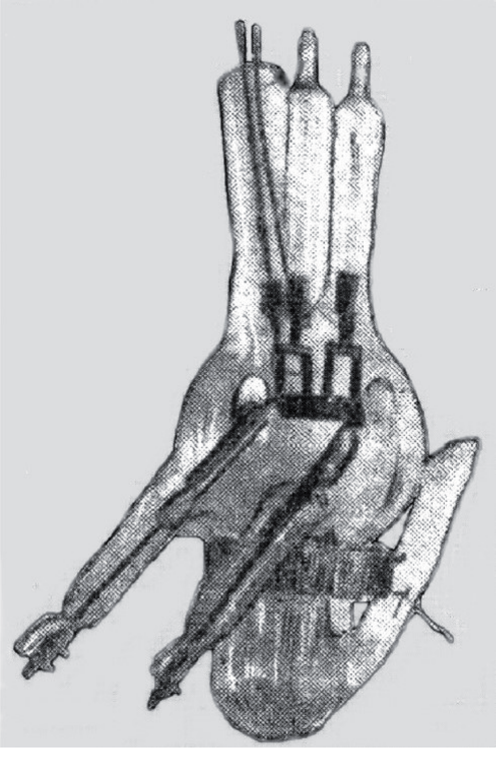


Figure 17. A magnetron with water cooling in a glass case: $P = 7$ kW, $\lambda = 80$ cm.

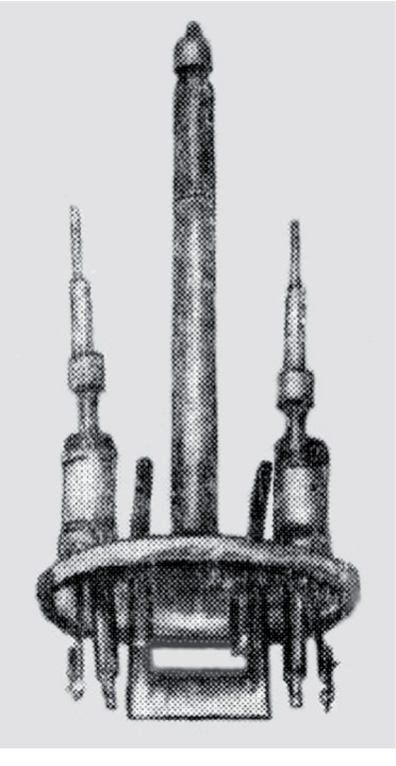


Figure 18. A magnetron in a metal case (removed): $P = 17$ kW in CW mode.

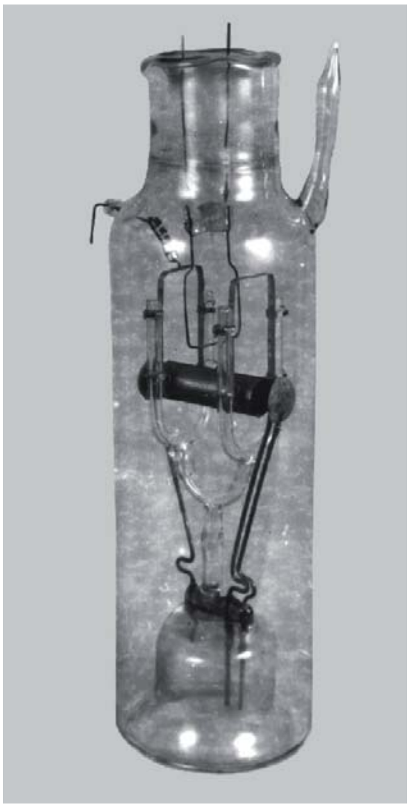


Figure 19. A pulse magnetron, $P = 60$ kW.

was achieved by Braude, in the all-metal "barrel-type" oscillator (Figure 18). Moreover, a tunable magnetron was designed, in which the frequency was tuned over a 30% band, by varying the length of the circuit extending off the metal case. These results were only published after the war, in 1946 [30].

At the same time, extensive investigations of the magnetron's power and frequency control, and the design of a pulsedmode device, were carried out. This work was led by Usikov. In 1933, Usikov discovered the effect of discontinuous modulation, which could be observed in a magnetron provided that its connection circuit corresponded to the relaxation scheme. Later he, together with colleagues [31], investigated the characteristic features of pulsed excitation in magnetrons. This work resulted in the design of high-power pulsed L-band magnetrons. At this time, a packaged un-cooled magnetron, with a linear cathode inserted in a glass case, was developed (Figure 19). It was implemented by Alexander Usikov, Ivan Truten, Iosif Vigdorchik (1910-1980), and Semion Braude. At the end of 1938, it generated pulsed power of 12 kW to 60 kW at a wavelength of 60 cm to 65 cm. Based on its own theoretical work, the UPTI thus created a series of magnetrons operating at wavelengths from 20 cm to 80 cm, with average power generation of 10 W to 100 W. More details can be found in [18].

It is worth recollecting that even earlier, the results on magnetron generators obtained by A. Slutskin were used in the CRL by Yu. Korovin's group when creating facilities for the radio detection of aircraft in 1934. Since September 1934, UPTI started to supply magnetrons of different powers and different wavelengths to the design bureau of the Red Army Air Defense.

By the end of 1936 [18], LEMO-UIPT had thus carried out a wide range of fundamental research on the magnetron method, and had a complete set of L-band devices, both for CW and for pulsed operation. This was a solid background for launching complex work on developing pulsed radar.

5.3 Development of the Pulsed Radar "Zenit" at UIPT

According to [2], from 1937, by decree of the PCD, the work on radio detection of aircraft for the air-defense alert service were to be the duty of the DC-RA via its body the Research, Development, and Testing Institute of Communications (RDTIC-RA): NIIIS, in Russian. Along with the problems associated with long-range surveillance for air defense, the RDTIC-RA initiated a parallel development of improved radars for anti-aircraft artillery. Having studied the state-of-the-art of the preceding developments, the experts of the RDTIC-RA concluded that they should employ the pulsed method.

The UIPT, foreseeing and following the general trend of the developments in the field of microwave radio engineering, began – earlier than other institutions – its own theoretical and experimental research in the field of generating electromagnetic waves using magnetron methods in L band, S band, and in the even shorter centimeter bands. Subsequently, these studies were a significant contribution to the development of radio-detection equipment, not only for their own needs, but also for their Leningrad and Moscow colleagues.

Further studies in this area were carried out in the LEMO at UIPT, and Abram Slutskin was the Head of the Laboratory from 1930. Based on the successful development of the generators, by the end of 1936 Slutskin launched an ambitious project on the development of the first pulse radar. This was able to determine all three coordinates of a target, while all modern (at that time) experimental systems were designed to determine only two coordinates of a target. Beginning in March 1937, in accordance with the task that was formulated by the RDTIC-RA, the UIPT officially started the design of an L-band pulse radar for anti-aircraft artillery [32]. It was tentatively named "searchlight," and had to operate at a wavelength of 60 cm to 65 cm.

In July 1937, the draft of the short-range radar for air targets (that was the name of the system for anti-aircraft artillery) was ready. It was equipped with a purposely developed magnetron of 1 kW power at a 68 cm wavelength [2].

This work, coded "Zenit," was performed under the guidance of A. Slutskin by the staff of LEMO: S. Braude,

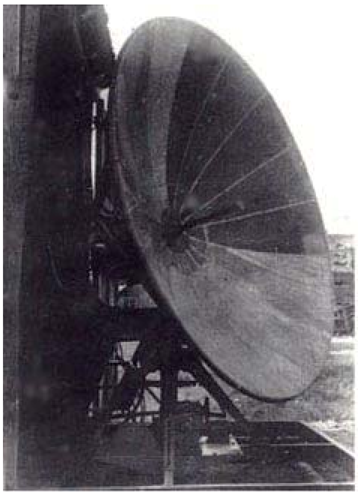


Figure 20a. The Zenit antenna.

Figure 20b. The transmitter located on the back side of the radiating reflector of the Zenit antenna.

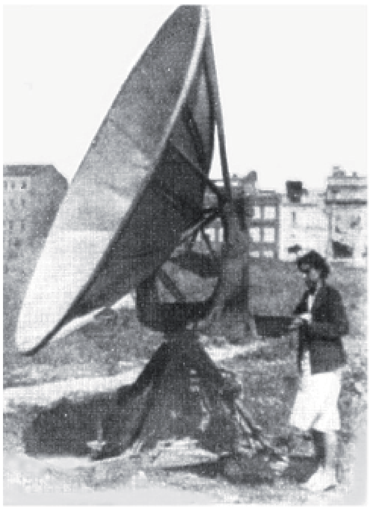


Figure 20c. Another view of the Zenit antenna.

A. Chubakov, Y. Kopilovich, P. Lelyakov, A. Maidanov, I. Sorkin, I. Truten, A. Usikov, and I. Vigdorchik, who contributed at various stages and to various extents.

In the middle of 1938, the first test of the "Zenit" prototype was fulfilled by detecting a small airplane. Some details of this radar prototype's development were found in Usikov's archive, which has partially survived [34]. In addition, a lot of interesting facts were revealed from interviews with S. Braude, A. Usikov, and other participants in the events or their younger colleagues [11, 15, 33]. It is interesting to follow the features of the systems and its principal components.

5.3.1 Features of Radar Design

A. Usikov described this radar as a two-antenna laboratory setup, in which the reflector antennas of the transmitter and receiver were separated approximately 50 m from each other, in order to reduce jamming of the sensitive receiver due to the high-power pulses of the transmitter. Both reflectors scanned in a synchronous manner in the horizontal (0°-360°) and vertical (0°-90°) planes, thus providing a stable, parallel orientation of the antenna-pattern axes [33].

A transmitter was located on the back side of the radiating reflector, in a hermetically sealed metal case. A two-wire feed, inductively connected with the magnetron circuit, was loaded with a half-wave dipole placed in the focus of the paraboloid of revolution. The receiver's reflector was of similar design, with the circuitry located in a hermetically sealed case at the back. Synchronized rotation of the reflectors was achieved by using selsyns.

5.3.2 Antennas

The antennas used identical all-metal parabolic reflectors, 3 m in diameter, fed by in-focus half-wave dipoles (Figure 20). A. Usikov recalled that manufacturing of the parabolic reflectors required a lot of sheet metal with a good environmental resistance. He hence he came up with the idea that it could be made of galvanized iron. This led him to a necessary but also risky action. Somebody in his team noticed that the institute buildings were equipped with rather impressive rainwater pipes, about 30 cm × 30 cm in cross section, made of what was needed. One night, all these pipes were taken off, flattened, and used to make reflector segments. Usikov was fined as the initiator of this action [33]. Reflector-antenna theory did not exist in the 1930s. Nevertheless, we can see that the "optimal" way to build the reflectors was found, although the performance characteristics of such antennas probably were far from optimal. The beamwidth of the amplitude radiation pattern of the antenna was about 16° in the "equatorial plane."

5.3.3 Transmitter

The development of the transmitter was led by A. Usikov, with I. Vigdorchik and P. Lelyakov participating. The transmitter was actually a magnetron source with a stabilizing resonant circuit. It was important to find a proper way for pulsed excitation of magnetrons. This led to comprehensive testing of several magnetrons, with different cathodes and anodes. Assembly, adjustment, and the first tests of the Zenit setup were carried out by using an un-cooled packaged magnetron. A modulator was connected in series with the magnetron. It used standard GK-3000 tubes. A relaxation-generator circuit, exploiting the TG-212 thyratron, was selected as a control device.

The first variant of the radar transmitter, in 1938, had the following parameters: wavelength, 60 cm; pulse power, 3 kW; pulse duration, 7 µs to 10 µs; magnetron voltage, 18.3 kV; pulse current, 20 A; magnetron lifetime, 50 hours. In 1940, the modernized Zenit radar used a new magnetron, with a pulse power of 10 kW to 12 kW, a wavelength of 64 cm, and a pulse duration of 10 µs to 20 µs.

5.3.4 Receiver

S. Braude, Y. Kopilovich, A. Maidanov, and I. Truten were responsible for the development of the receiver. First, they designed an original magnetron receiver, where a double-anode magnetron was used as a super-regenerative detector. This receiver enabled them to carry out the tests of detecting an airplane using the first version of the Zenit radar (1938). However, this could not serve as the basis for developing a radar able to meet the requirements of the anti-aircraft artillery, due to the strong dependence of the receiver's sensitivity on the magnetic field and the magnetron's emission current. That is why, along with this device, the research team had investigated a super-regenerative receiver based on the 955 type of acorn tube (a triode). This had a much higher sensitivity, and was implemented in the modernized version of the Zenit radar. Later on, to enhance the sensitivity of the receiver, I. Truten developed a superheterodyne receiver with an L-band amplifier (1940).

5.3.5 Calibration and Testing

In the summer of 1938, an experimental electromagnetic Zenit "searchlight" was assembled. Preliminary calibrations of the receiver and transmitter were done by Truten and Kopilovich at the 8 km line-of-sight test range between the UIPT hillside compound and the Kharkiv Tractor Industry [33]. The first tests of aircraft detection were carried out on October 14, 1938. The receiver and transmitter antennas were placed at a distance of 65 m from each other, and the optical axes of their reflectors were fixed to be parallel at elevation angles of 20°. An SB-type middle-sized bomber flew at a distance of 3 km from the radar, crossing the radiation pattern of the antenna system. Under such conditions, a stable effect of reflection of the decimeter waves from the aircraft was observed. On this basis, the conclusion was made regarding reliable detection of the aircraft at a distance of 3 km. This result was quite appropriate for the beginning of the work [2]. It was of the same order as the first research results, obtained at CLR and LEPI (Section 2), but it was obtained using the pulse method instead than the continuous-wave method.

The test results enabled the designers to understand what should be done to improve the performance of Zenit. Satisfied with the first results, the CD-RA allocated a new project to LEMO-UIPT in May 1939. The task was to increase the radiation power and to improve the reliability. The modernized prototype radar had the following performance specifications: a wavelength of 64 cm; a pulse power of 10 kW to 12 kW; and a pulse duration of 10 µs to 20 µs [2]. It was under preparation to be transferred to industry.

In less than four months, WWII started in Western Europe. In about three weeks, it was accompanied by the Soviet campaigns against Poland, the Baltic States, and Finland. This added the zeal of military-oriented research and development work.

In September 1940, a modified Zenit radar was presented to interested customers for tests. The Department of Air Defense, the Red Navy, the PDA-PCD, the RDTIC-RA, and others were among them. Investigation of detection possibility and coordinate determination was done on a single airplane and on a group of airplanes. S. Braude was an eyewitness of this test. In his interview [11, 15], he recalled:

> The mission of a bomber was to execute several turns on the flight course. First it flew away from the radar for 50 km, then turned right, flew 50 km more, then turned back, flew 100 km, and so on, repeating this route six times.
>
> During the fifth circle, the pilot turned to the opposite side, as he did not seriously consider the experiments and hoped that this deviation, in the clouds, would not be detected. He was deeply impressed that his unplanned maneuver was recorded at the ground-based station. From that moment, he became an active zealot of radar and played an important role in the fate of the Zenit project.

The final report on the test results (1940) [34] confirmed the following. The device was able to determine the three-dimensional position of a single aircraft at various heights. The range of the reliable detection and three-dimensional target-position determination at altitudes of 4000 m to 7000 m was 6 km to 25 km. At ranges of 25 km to 35 km, the detection was less reliable. Two tests were done to estimate a relative measurement accuracy. Comparisons of the airplane altitudes determined by the Zenit radar with the barograph indications revealed an average difference 8.9% in the first test, and 5.2% in the second test.

The times required to determine the target coordinates were as follows:

a. two coordinates, elevation and range: 13 sec;
b. two coordinates, azimuth and range: 17 sec;
c. three coordinates, elevation, azimuth, and range: 38 sec.

Interesting conclusions were drawn from the observations of squadrons with the Zenit radar. A group of airplanes was reliably detected at heights of 3000 m and 4000 m in the specified space sector. If a squadron was flying in tight order, the oscilloscope indicated the beating of pulses reflected from each aircraft. If one of the airplanes was behind the others, one could observe the variation of the width of the maximum corresponding to the reflected signals. If a squadron was flying in a column, with the airplanes separated by 2 km, the oscilloscope screen clearly indicated the pulses reflected from each individual aircraft, in the form of isolated maxima. Even some results concerning target resolution were obtained [34].

The generalized basic results of those tests according to [2] showed the maximum range of reliable detection of a single SB-type airplane was 25 km, and of a group of planes was 30 km. The measurement accuracy was 1 km on range, 3° to 4° degrees in azimuth, 1° to 2° degrees in elevation angle, and 10% in height.

Estimating the overall results of the Zenit tests, the state commission officially asserted [2] that the Ukrainian Institute of Physics and Technology (UIPT) had designed the first experimental setup that enabled locating a flying airplane in three coordinates (distance, azimuth, and elevation). Later, General Lobanov [2] wrote that it was a great success for the young UIPT team. Compared with the experimental radio searchers "Burya" and B-2, developed at RDI-9, the Zenit prototype had considerable advantages for the detection range, and the ability to determine all three coordinates that are necessary for shooting air-defense artillery, which was a very important quality in that time. Neither the British Chain Home nor the German Freya (which were perhaps the most advanced radar systems in Western Europe) could estimate both target azimuth and elevation angle along with target range.

However, due to some shortcomings of the Zenit prototype, the UIPT was forced to continue the work on its improvement. The first drawback was the inability to continuously determine the coordinates of the airplane and to enter them into the antiaircraft director in preparing data for anti-aircraft firing. Zenit could periodically determine target coordinates: as mentioned above, for the evaluation of all three coordinates, 38 seconds were required.

The second drawback was the difficulty in target search due to the narrow antenna pattern, similarly to radio searchers Burya and B-2, developed by RDI-9.

The third drawback was the presence of a dead zone of radius 6 km, within which anti-aircraft artillery could not fire. Meanwhile, this area was the most effective in shooting with guns of 85 mm caliber.

Finally, it was stated that the three-coordinate Zenit prototype couldn't yet serve as a basis for the industrial production. The Committee recommended that UIPT finalize the design of the station to improve the reliability of aircraft detection and accuracy of height determination, and provide continuous determination of the coordinates.

Having limited funds and production capacity, the Ukrainian Institute met with considerable difficulty in manufacturing this device [2]. Under such conditions, the fact that a group of able young scientists at UIPT not only succeeded to make the theoretical calculations and experiments necessary for developing a laboratory version of the Zenit pulse radar, but had managed to produce the radar setup on its own, was credited to the efforts and enthusiasm of the team.

In [11], a comment was made that helped better understand the situation at UIPT in that time. Along with the technical problems mentioned, the working conditions at LEMO were certainly inadequate in 1935-1938, because of the general atmosphere at UIPT during the years of Stalin's terror. At that time, the UIPT, a leading research center, was literally smashed by a series of severe repressions, with Lev Landau being the main target [26].

United by a common goal, Slutskin's people kept perfectly friendly relations, despite sharp discussions [15]. However, the climate in the institute was not favorable for healthy working conditions. Some of the UIPT scientists were arrested; others were interrogated; frequent political meetings of the communist party, trade union, and Komsomol brought fear and embarrassment to the collective.

In addition, some of the leading scientists – first of all, the theoreticians – displayed neglect towards the radiophysics research, considering it second-rate physics. The gap became even deeper when UIPT started working on defense projects, which dominated in research and development carried out by LEMO. The Ukrainian historians of science Y. Pavlenko, Y. Ranyuk, and Y. Khramov wrote [26] that exactly the latter point was at the very core of the conflict at UIPT.

When the defense-oriented research was started at UIPT, most scientific leaders of the institute who normally determined the science policy were not involved into the new defense themes. The reason was not fully clear. Somebody could refuse to participate in the military projects, feeling that this would inevitably limit the freedom of research. It could also have been possible that they were not allowed to do so by the then-director of the institute or by the NKVD/KGB. Meantime, military projects had preference; moreover, the scientists involved were paid greater salaries. This resulted in splitting the institute into two conflicting groups, each of which had its sympathizers beyond the institute. In accordance with [35], part of the UIPT scientists, including Landau, proposed to separate LEMO from the UIPT. In fact, further developments proved that this could have been the best solution. The matter was that in the atmosphere of a search for enemies in the 1930s, this internal conflict was actively exploited by the NKVD. Fortunately for LEMO, work on the radar project played the role of a protective shield, thus allowing them to study the fundamental microwave problems, as well.

It can be added that this was always a common practice: in the early 1950s, the leaders of Soviet physics successfully used nuclear programs to save the theory of relativity and quantum mechanics from the Stalinist ideological mobsters, while the less-fortunate fields of genetics and cybernetics (computer science) were crushed [36]. In this connection, from the view of the story on Ukrainian radar development, the most important point is that Lev Landau, the indisputable informal scientific leader of UIPT, who was really a very bright personality, did not stay away from this internal conflict. All who left their opinion in any form [35], including the NKVD informers whose observations were summarized in the voluminous file on Landau in the KGB [37], agreed that Landau's attitude toward the radar project at LEMO (and so personally toward A. Slutskin) was negative. Although this was his general attitude toward the military research in the USSR throughout all of his life, he later never openly expressed it [37], and he had reasons for this. It was only his worldwide fame that saved him in 1937, when the NKVD pointed to him as a leader of the "Trotskyist-sabotage group" accused of "trying to spoil defense works in UIPT" [26]. Landau then escaped to Moscow, to work in the Institute of Physical Problems of Piotr Kapitsa. Nevertheless, he was arrested in 1938, and spent one year in the NKVD jail before being saved, both for science and life, due to the extraordinary efforts of Kapitsa (who personally appealed to Stalin). Later, along with many other Soviet scientists, he used military nuclear-program research as a shield against the persecutions [36].

Working on overcoming the indicated drawbacks, UIPT also tried to increase the energetic potential of the Zenit setup to increase the detection range. In 1939-1940, the situation inside UIPT became somewhat more favorable for LEMO. The work schedule of the laboratory for 1941 foresaw solving the problems around the improvement of Zenit, and the development of a single-reflector pulse radar, Rubin.

However, the beginning of the war on the territory of the USSR infringed on these plans. It is well known that Moscow experienced its first air raid on the night of July 22, 1941. Under these circumstances, the DC-RA offered to check the feasibility of using the Zenit system in combat situations for the air defense of Moscow [2]. Even before, at the very beginning of the war, the pilot who took part in the 1938 tests of Zenit in Kharkiv wrote a letter to Stalin, and urged him to deploy this promising detection system [11]. On August 16, the LEMO staff members S. Braude, A. Chuhakov, L. Kitaevsky, Y. Kopilovich, A. Maidanov, A. Slutskin, A. Terpilo, I. Truten, A. Usikov, and I. Vigdorchik were sent to Moscow, and added to the RDTIC-RA. They brought the experimental Zenit radar, which was installed in the town of Mytishchi, into combat service. The radar was connected directly with the command post for air defense in Moscow. The certificates given to A. Slutskin in his mission to Moscow for testing the radar are shown in Figure 21. They played the role of identification, guaranteeing a safe passage to Moscow [11].

Braude [15] told about an occurrence that happened during their work in Mytishchi. A group of soldiers were assigned to the radar team. The moral atmosphere at the beginning was full of tension. Of course, people did not have any understanding of the radio-detection principle, and groups of healthy men staying in the rear could be considered to be escaping from military service. The situation changed when the team succeeded in detecting by radar that, during a raid on Moscow, one of the German bombers left the flight order and made a loop to the east. Thanks to a report to the air-defense command post, this bomber was shot down by the antiaircraft artillery.

In September 1941, after further testing, the commission, chaired by the deputy commander of the air defense corps, Colonel Makeev, noted [2]:

- The station could not detect near-flying aircraft within a range up to 15 km, because of reflections from local objects;
- The detection range was 60 km at flight heights above 5000 m;

Народный Комиссариат Обороны Союза ССР

УПРАВЛЕНИЕ
ЗОНЫ ПВО
ХАРЬКОВСКОГО
ВОЕННОГО ОКРУГА
15 9 дня 1941 г.
№ 234
г. Харьков

СПРАВКА

Тов. Слуцкин А.
командирован в гор. Москву в рас
жение НКО, для участия в провед
[illegible] спецустановки.

ОСНОВАНИЕ: Распоряжение Пред
теля Государственно
Комитета Обороны СССР

[illegible] до 15.10.41 г.

ЧАЛЬНИК ШТАБА ЗОНЫ
ПВО ХВО
КАПИТАН /ПАЛЕХА /

РНК—УРСР
АКАДЕМІЯ НАУК
ФІЗИКО-ТЕХНІЧНИЙ ІНСТИТУТ
Харків 24. Юмовський тупик, телефон 7-22-23 и 7-22-24.

№ 9 16 августа 1941 р.

СПРАВКА

Тов. СЛУЦКИН Абрам Александрович командирован в гор. Москву в распоряжение НКО.

ОСНОВАНИЕ: Распоряжение Председателя Государственного Комитета Обороны СССР.-

Зам [illegible] АН УССР -/ШПЕТНЫЙ А.И./

АК.

укнiп. 517—550

Figure 21. The certificates given to A. A. Slutskin in 1941 for the journey to Moscow and participation in the tests of "Zenit" in combat conditions.

- The mean location error was 2.5° in azimuth, and not more than 1.5 km in height.

The tests demonstrated that after improving the radar, the detection range increased by a factor of two, but the dead zone also increased by more than twice. The commission noted that the present Zenit radar could not be employed for precise aiming and tracking of anti-aircraft artillery, but its accuracy was sufficient for barrage fire. Besides, this station could be used for the guidance of fighter aircraft, as supplementary equipment to the RUS-2 surveillance radar (see Section 7). Further modifications could be developed only under laboratory conditions. However, such work was not possible at that time, neither in Moscow nor in Kharkiv. Because of the evacuation of the RDTIC-RA to Bukhara, on October 17, 1941, the Zenit radar and the whole LEMO team were dispatched there.

In the meantime, UIPT itself was already on its way to central Asia. As is known, in the summer of 1941, the situation on the Soviet-German front dramatically developed. In the first days, the cities of Riga and Minsk were lost, and rather soon, the German tank armies were threatening Moscow. The more-successful defense of Soviet troops in the Kiev direction put a serious strategic problem to the German commanders. On August 23, 1941, at a meeting in the headquarters of the "Center" group of armies, Hitler rejected a proposal by General Guderian to concentrate all the forces for an offensive on Moscow, and decided to attack East Ukraine from the north. Kharkiv, which is located to the east behind Kiev, was in the mainstream of the new German offensive. After the fall of Kiev, at the end of September, the fate of Kharkiv was determined, and on October 24, the Red Army left it. However, much earlier, in July 1941, the State Defense Committee had decided to evacuate the heavy industries of Kharkiv to the east. Obviously, the UIPT was not an industry, but it was still considered a valuable organization, and had to be evacuated, as well.

6. Development of the Single-Antenna Radar "Rubin"

In 1939-1940, along with designing the Zenit radar, LEMOUIPT performed three research and development projects for the CD-RA: "Generator and Receiver Operating in cm-Band," "Application of the Independent Excitation Principle for Generating Frequency-Stable dm-Band Pulses," and "Design of a High-Power Pulse Source at dm-Band Stabilized by a Resonant Circuit" [2]. The results of these studies, as well as the experience accumulated during development and testing the Zenit radar, enabled LEMO to proceed with the design of the "Rubin" radar in 1941. This system had to have increased target-detection range and improved accuracy of target location. Nevertheless, perhaps the most interesting aspect was the development of the single-antenna system for both transmitting and receiving. Unfortunately, the rapid approach of the front line forced LEMO of UIPT to stop working as early as in July 1941, and to pack the equipment for a long trip. The final destination for the UIPT was Almaty, Kazakhstan; except for LEMO, which was evacuated to the city of Bukhara, Uzbekistan, over 3500 km away from Kharkiv, and 1500 km from Almaty. Located in the heart of Central Asia, Bukhara city had a glorious past. Before 1920, it was the capital of the Emirate of Bukhara, a multi-national Muslim country that was under the protectorate of the Russian Empire.

In fact, the separation of the radiophysics laboratories of UIPT that was proposed by "pure physicists" in 1937 was thus done by the war: the LEMO was separated from the

Figure 22. The group from UIPT and RDTIC-RA in Bukhara, February 23, 1942.

other departments of UIPT. After WW II, UIPT returned to Kharkiv, and all its laboratories were again working together. Here, history took a curious twist [11]: in the 1940s and 1950s, the Institute was a major research and development organization behind the NKVD-managed nuclear project code-named "Lab No 1." At that time, all the departments of the UIPT enjoyed the benefits of working on extremely important defense topics, except for two radiophysics departments (the former LEMO, headed by Slutskin, and the new Department of Radio-Wave Propagation, headed by Braude). Obviously, to avoid new conflicts and also due to a rising interest in developing mmwave plasma-diagnostics technologies for Tokamak fusion machines, it was decided to separate these departments from UIPT, and to establish a new institute, the IRE. It is worth noting that Slutskin was against this separation, which was approved only after his sudden death in 1950.

However, let us go back to Bukhara of 1942. The work on the Rubin project was resumed there, in collaboration with the RDTIC-RA, which was also evacuated to Bukhara (Figure 22). The scientists of RDTIC-RA, M. Kulikov, K. Motorin, and N. Nechayev, actively participated in this work. By that time, LEMO had lost some of its leading staff members, including Lelyakov, who remained in Kharkiv. In place of Lelyakov, L. Kitayevsky joined the project as a radio engineer.

In order to eliminate drawbacks found during the tests of the Zenit device, the causes of the errors due to the direction-finding technique selected (a null-reading method) were analyzed, and several methods of continuous detection were considered. As a result, a continuous-location scheme, utilizing the stationary-dipole method, was selected. Its implementation and accuracy were tested, and the key blocks were finalized. However, the lack of necessary industrial capacity (radar was then produced in Tashkent) resulted in a failure to apply the new scheme for target location.

The receiver and transmitter circuits of the Rubin radar were similar to those of the Zenit. However, to increase the power and stability of the source, and to raise the sensitivity of the receiver, some corrections and changes were introduced in the design. The pulsed power of the magnetron was increased up to 15 kW. The improved receiver was essentially a wideband superheterodyne, with double frequency conversion. It had a high-frequency part (an L-band amplifier, the first mixer, and the first heterodyne), and an intermediate-frequency amplifier, all placed in a hermetically sealed case on the back of the antenna reflector. The power-supply unit, the remote-adjustment blocks, and the amplifier control console were located in a truck. The heterodyne wave meter, for controlling the source frequency, was also placed there. While developing the Rubin radar, Truten had succeeded in solving the extremely "hot" problem of providing the operation of a radar with a single antenna and also protecting the receiver from the impact of a high-power source pulse. This was done by employing a gas discharger, which blocked the input of the receiver circuit when a high-powered pulse arrived. As an additional measure, blocking of the intermediate-frequency amplifier's first cascade was provided.

Figure 23. The antenna unit of the single-antenna radar "Rubin."

S. Braude recalled [15] that I. Truten was an innovator with extraordinary capabilities. A fundamental approach was always present in his research, and was especially brightly displayed later, when he guided the work of developing the mm-band magnetrons in the 1950s and 1960s at IRE, enjoying huge respect among the staff.

The antenna of the Rubin was designed as a paraboloid of revolution, 3 m diameter, with transmitter and receiver dipoles located in the focus (Figure 23). The dish was deployable, and consisted of six removable segments, made from 2-mm diameter wire. As recalled by Usikov [33], the wind loading was really strong for such large-size reflectors. Hence, it was clearly necessary to resort to a mesh-antenna design. These were made from wires stretched on the ribs, and soldered with a spacing of 20 mm × 20 mm. All this was handmade by the team members.

The beamwidth of the antenna pattern's main lobe (at the halfamplitude point) was 16° in the "equatorial plane," and 24° in the "meridian plane." The magnetron source, with a resonant circuit, and the receiver circuit were housed in a hermetically sealed case on the back of the reflector. Rotation of the antenna in the vertical (0° to 90°) and horizontal (0° to 400°) planes was remotely controlled. These data, together with the terminology, were based on the memories of those who heard them from the designers, because there is no technical documentation available about Rubin and its antennas, or about the Zenit system.

All of the Rubin equipment (Figure 24) was placed on two cars: one for the power supply (a ZIS-6 truck), and another one for the electronics (a GAZ-3A truck). On the first car, the antenna system was installed on special rails.

Figure 24. The full set of the Rubin system.

When the radar was deployed at a combat position, it was rolled out. A control console and a power-generating unit were also placed there. That consisted of a three-phase generator (PNT-100) and a petrol engine (L-12). The modulator unit and the oscilloscope display, together with the antenna's remote-control system, were located on the electronics vehicle. The deployment and setting-up of the Rubin radar took about three hours.

In 1943, Rubin was transported to Moscow, where it was tested until November. In early 1944, the DC-RA sent the Rubin radar to a polar port and naval base in Murmansk, according to the agreement with the Red Navy Command. From February 1 until March 31, 1944, tests of the radar were performed there, led by Usikov. The place for the deployment of the radar was at the Kolsky Bay coast in the Vayenga Fiord. There, the maximum width of the fiord was 4750 m. The bay offered a variety of testing opportunities, due to intensive sea traffic: Soviet and foreign navy ships and convoys frequently used Murmansk as the single non-freezing port in the Soviet Arctic. The following were the data regarding detecting airplanes and ships found in Usikov's archive [34].

6.1 Aircraft Location Tests

The tests were normally carried out to detect occasional airplanes.

To verify the accuracy of target location, a Hawker Hurricane once made a purposeful flight along the specified route. When flying over the sea, it was first detected at a distance of 60 km. Determination of the airplane's position at a distance of 40 km was reliable. During the tests, the Rubin system was able to detect the airplanes many times, which flew at very low altitudes (30 m to 50 m).

The average errors of estimating coordinates were up to 120 m in range, and no more than 0.8° in azimuth and elevation. The time required to measure any of angular coordinates never exceeded seven seconds.

6.2 Ship Location Tests

It should be noted that the area of testing was a relatively small, open space, and the rocky coast was 5 km from the radar. It was rather complicated to make tests under such conditions. Despite this, the tests showed that:

- "Rubin" detected all types of ships – cruisers, destroyers, transport ships, surfaced submarines, motor boats, and even wooden boats – at distances from 500 m to the limit of available range, that is, about 5000 m.
- The amplitude of the reflected signal was dependent on the type and size of the ship.
- The amplitudes of the reflected signals were not stable: they changed in time, with the fluctuation frequency depending on the vessel's size and speed.
- The average errors in the accuracy of determining the coordinates of targets were not more than 120 m in distance and 0.8° in azimuth.

Usikov was always proud of this achievement, and claimed that their team, led by Slutskin, received the best results in radar in the USSR at that time. Up to the end of the war, Rubin worked in the polar sector of the Soviet-German front for air and naval surveillance. Nevertheless, this unique and promising radar system was never launched into mass production. We do not have a clear explanation of that fact.

7. Observation of the Atmospheric-Duct Effect in Bukhara

During the work in Bukhara, LEMO scientists saw a mysterious phenomenon, which had never been previously reported. In the notes by Usikov [33], it was described the following way.

At a time when the tests of the new Rubin radar were in full swing, the specific effect of intensive repetitive noise practically spoiled all the work. It was manifested in the form of unusually strong reflections of the type of terrain objects, but at all ranges within a radius of 180 km. It was a kind of "blindness" of the radar, which suppressed the radar signals, reflected not only from the aircraft but also from local objects that acted as landmarks.

Powerful interfering reflections were observed in May to July 1942 by Usikov, Truten, and Vigdorchik. The reflections occurred at different times, usually in the afternoon, and their origin was difficult to understand. Scanning the antenna beam within the sector of 90° in azimuth and 70° in elevation was practically useless. These difficulties often even forced the researchers to cancel the planned tests.

This phenomenon had never been observed, either in Kharkiv nor in Moscow, but was manifested in Bukhara. Usikov and his colleagues therefore named it the "Bukhara effect." They guessed that the nature of this phenomenon might be due to extreme weather conditions, typical for the sandy desert terrain in the vicinity of Bukhara. More specifically, they concluded that the effect of Bukhara was caused by a sharp decreasing natural attenuation of decimeter waves propagating over the deserts of Kyzyl Kum and Kara-Kum. This made it possible to observe strong radar reflections from the local objects, located on the all way from radar to the Aktau mountain, 150 km to 180 km northeast of Bukhara. The inability to avoid these reflections by rotating the antenna was attributed to a multi-lobe directional pattern [33, 38]. Recall that the first description of the surface-waveguide propagation effect (an atmospheric duct) was given in 1946 [39]. Inside the natural channel (duct), the electromagnetic field propagates as a cylindrical wave, instead of as a spherical wave in free space, although other mechanisms exist.

As a result, the maximum range of the L-band radar under the special circumstances could exceed the range in free space by 15 times or more [40]. Normally, the ducting effect was observed over the sea. According to [41], the long-distance record was 1700 miles, between India and Arabia.

These observations and the discovery later led S. Braude to new results and the creation of the over-the-horizon radar in Kharkiv, after the war. The work on the over-the-horizon radar was started there, using decameter and hectometer waves. The work was successfully continued at home, after Kharkiv was liberated in 1943.

In 1952, S. Ya. Braude et al. were awarded the State Prize (then, the Stalin Prize) for this work [32].

8. Radar for Long-Range Detection

8.1 The First Work in LIPT

In the summer of 1935 A. F. Ioffe (Figure 25), the director of LIPT, organized a special laboratory for work on the problem of aircraft detection at his institute. D. Rozhansky, who earlier worked in Kharkiv, was assigned to be head of the laboratory. The reader will remember that in Kharkiv, Rozhansky met Yuri Kobzarev, a student of KhSU who assisted him with measurements; Kobzarev was then invited to Leningrad as his assistant. Rozhansky also invited V. I. Bunimovich, another of his pupils from Kharkiv (UIPT), to join his lab [53]. Bunimovich (together with his teacher) developed the basics of the hollow resonators that were important elements of radar transmitting devices. Later, Kobzarev recalled [5] that at the beginning of the work in Leningrad, Joffe invited him to his office, and directly said that the main task of the laboratory staff was creating pulse technology for radio detection.

When Kobzarev arrived at the laboratory, two young people – N. Chernetsov and P. Pogorelko – already worked there. They both were students engaged in degree theses under the supervision of Rozhansky. Chernetsov was engaged in the design of broadband IF amplifiers, and Pogorelko was engaged in the design of a reference oscillator to calibrate the receiver. The issues of antenna-feed device development, plus creating an input converter and an output device (later, the oscilloscope electronic device), became the basic tasks of Kobzarev (Figure 26).

It was necessary in the short term (by the fall of 1935) to produce equipment that would allow obtaining

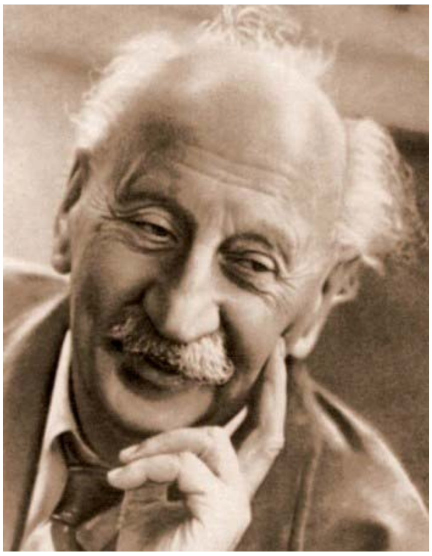


Figure 25. Abram F. Ioffe.

Figure 26. Yuri B. Kobzarev.

Figure 27. A. Maleyev (laboratory assistant), Yu. Kobzarev, P. Pogorelko, and N. Chernetsov (1937).

quantitative characteristics of the reflection of radio waves by aircraft in the real world. The first experiments were carried on with a continuous-wave transmitter.

Although the basic equipment was developed in Leningrad, the test was planned in the suburb of Moscow. In the laboratory of P. Oshchepkov in Moscow, the transmitter was developed, operating in continuous-wave mode with a carrier wavelength of 3 m to 4 m, modulated by a 1 kHz oscillation. In the winter of 1935, the equipment was brought to Moscow, where the first major test was held. During this test, Kobzarev wrote [5] that a lot of valuable material for further work was obtained.

Oshchepkov's transmitter was located in the building, while the antenna was installed on the roof. The receiver was of the superheterodyne type, and had a wide bandwidth (because it was supposed to be used for receiving pulses). The detected signals from the IF output of the receiver were used to excite the oscillating circuit of high Q, tuned to the transmitter's modulation frequency.

The set of equipment also included a reference oscillator, developed by Pogorelko, which was used to test and calibrate the receiver. Both devices were powered by batteries, and could easily be transported from place to place.

The receiver was installed at various points in the area of the airfield near Moscow. An airplane flew around it in circular paths of different radii and at different heights. The signals reflected from the airplane were manually read and recorded.

The radiating and receiving devices in this system were located along a line parallel to the border being defended. The intersection of this line by the airplane could be reliably recorded. Such a system was later developed, and in September 1939, put into service under the name "RUS-1."

This was operated in 1940 on the Karelian Isthmus, during the Soviet-Finnish war. However, there were difficulties with the determination of an airplane's identification, and during the German-Soviet war, the system "RUS-1" was relocated to a less-critical part of the border, in the Caucasus and in the Far East. It was later replaced by the pulsed radar "RUS-2" and "Redut," which had incomparably better quality.

By the end of 1936, the preparatory work for testing the pulse method itself was completed in LIPT. At this time, the leader of this work, Prof. Rozhansky, passed away. Management was transferred to Yu. Kobzarev.

8.2 The First Tests of the Pulse Method

The beginning of tests was delayed due to difficulties with transmitter development in the labs at the Experimental Sector of the Air Defense Department, where the person responsible was Pavel Oshchepkov. Finally, in March 1937, the lab staff from LIPT (four persons) arrived in Moscow. In Figure 27, one can see all of the young LIPT team on the range of the Experimental Sector in April 1937. Fortunately, we have some details of the events and features of the equipment from the memories of the principal participant [5].

After checking their equipment, they waited until the powerful transmitter, installed in Moscow, would operate. However, they could not receive a signal from that transmitter: the task of control by the powerful pulse generator had not been resolved in Moscow. Nevertheless, the desire to carry out the planned experiments was so great that a small team created its own experimental setup for radio detection.

They used the reference oscillator added by a control oscilloscope, and a modulator that converted the continuous radiation into RF pulses. Such a pulse modulator with the reference oscillator operated as a master oscillator. They hastily constructed an amplifier circuit for the RF pulses. The amplified pulses were applied to the grids of VHF vacuum tubes, which were controlled by these pulses. Such a pulse generator was a low-power transmitter (about 1 kW pulse power), but worked quite stably.

The pulse-repetition frequency was about 1 kHz, and the receiving oscilloscope device was designed for exactly the same frequency. It had a CRT at the output, and the voltage from the last oscillation circuit of the IF amplifier was applied directly to the deflecting plates of the CRT.

Because of the low radiated power, the maximum range of such an experimental setup was rather small. Nevertheless, the observations of the RF pulses reflected from the airplane, implemented with the help of this

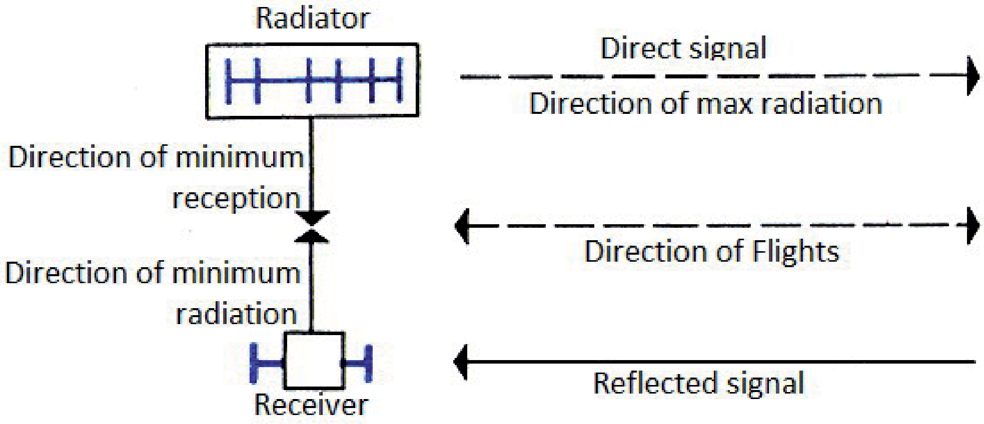


Figure 28. The layout of the experiment done by Yu. Kobzarev and his team in 1937 [5].

equipment, had a decisive influence on the entire course of further work.

From a modern viewpoint, this setup was equipped with a rather strange display. The oscilloscope's sweep was a helical curve. The beam-deflection voltage in the horizontal plane from a special low-frequency circuit was applied directly to the plates, and the beam deflection in the vertical direction was produced by the action of the magnetic field of coils in the same circuit. The damped oscillations of that circuit were excited by a special device that operated synchronously with the sounding pulses, but a little bit earlier. This was done in order that the beginning of the sounding pulse and the start the reflected pulse could be clearly marked on the sweep (helical curve). Knowing the oscillation frequency of the sweeping circuit, it was possible to measure the angular distance between the beginning of the two pulses with good accuracy. The measured angular distance was proportional to the time delay of the reflected pulse, and the distance to the target (airplane) was therefore determined.

The receiving device was mounted in a small metal cabin, and the antenna was installed on the roof of the cabin. The cabin could rotate around a vertical axis. The antenna system consisted of two half-wave dipoles, coupled by a coaxial feeder with the input of the receiver circuit. A special device allowed adjusting the degree of coupling between the receiver and each dipole. The relative position of the half-wave dipoles, the direction to the transmitter, and the direction of the airplane's route created the conditions for mutual compensation (in the input circuit of the receiver) of signals coming from the transmitter to the dipoles, and adding the signals reflected from the airplane. The arrangement of the equipment in the experiments (in 1937) is illustrated in Figure 28. In this figure, the transmitting antenna consisted of six half-wave dipoles, and the receiving antenna consisted of two dipoles spaced by a distance equal to the wavelength. The distance between transmitting and receiving equipment was very large.

The first flight was on April 15, 1937. Yu. Kobzarev recalled: "Our excitement was very great; but we were lucky." The reflected signals were surely observed at those parts of the sweep that were not occupied by "local objects." It was recorded in the photographs in the form of short breaks of the helical sweep. A photograph of the screen that indicated the reflected pulse is shown in Figure 29. The angular distance between the beginning of the sounding pulse and the reflected pulse determined the range to the airplane. In the case given, it was 12.5 km. The altitude of the aircraft was given in advance, and in this particular case, it was 500 m.

Upon completion of work at the range, it was decided to help the Experimental Sector in the development of a powerful modulator for the transmitter, based on vacuum tubes. By the end of 1937, it was decided to finalize the one-point radar (monostatic system) with a detection range of at least 50 km. The LIPT and Air Defense Department

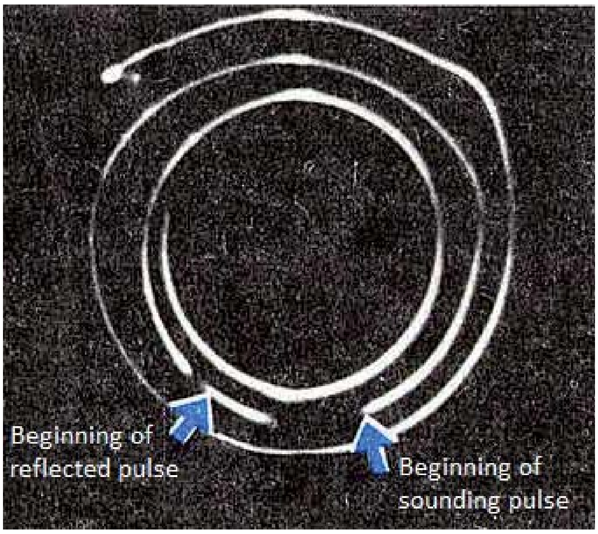


Figure 29. A photograph of the screen during an experiment in 1937 [5].

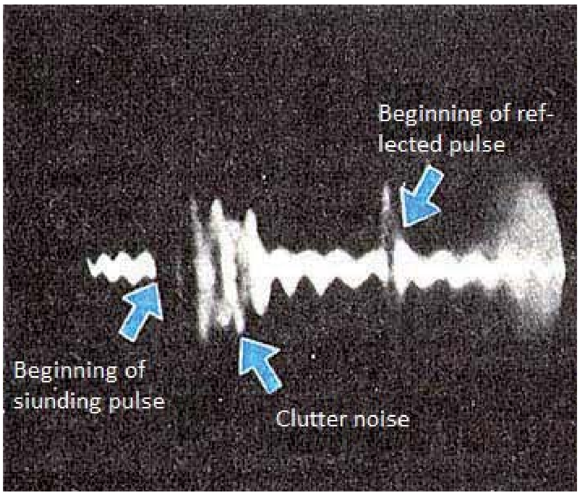


Figure 30. A photograph of the oscilloscope screen in the experiments of 1938 [5].

made a relevant contract, but the circumstances suddenly changed. In the summer of 1937, the Experimental Sector was eliminated. All its equipment and all the cases were handed over to the RDTIC-RA (NIIIS), subordinated to the DC-RA of PCD.

P. Oschepkov was arrested. He received 10 years in the Gulag. When his term ended and he was released, he never returned to the subject of radar, although he later became a professor and doctor of technical sciences in another field. In his memoir book [1], the second edition of which was published in 1976, he was allowed to write only the following: "In 1937 I moved away from the work on the radar, and to write its further history is not my business."

The LIPT was told to bring the work to the end on their own. Additional work and responsibility to develop a high-power transmitter led to an overload of the team, and to the delay of the entire work. Nevertheless, by the end of 1937, the development of the modulator for the powerful transmitter was nearly completed, but the generator operated with irregularities. Furthermore, it was necessary to fabricate apparatus that could be transported without damage, and to solve the problem of transmitting high-frequency pulses of high power from a closed space to an outdoor antenna in any weather. The final solution to all these issues was only completed in the summer of 1938.

The equipment was manufactured, transported to Moscow, and installed in two buildings spaced approximately 1 km apart. The buildings belonged to RDTIC-RA. One of the buildings was located on a hill, and had a small add-on to the top floor: a 4 m × 4 m room, with access to a small platform on the roof. Another building was located in a valley. The receiver and display device were located in the superstructure of the first building. The receiver was coupled with the antenna installed on the roof. The transmitting unit and a similar antenna were located in the second building.

Figure 31. A. B. Slepushkin.

When designing the transmitter, it was necessary to decide whether to keep a high repetition rate (about 1 kHz), on which work was carried out in 1937, or to be satisfied with a much lower frequency: the frequency of the power network (50 Hz). They used 50 Hz, in spite of the obvious disadvantage, just because it was much simpler and easy to do. Another change was made in the display, with the sweep made linear, not helical, as in the previous version. A picture of the oscilloscope's screen in the experiments of 1938 is shown in Figure 30. The line of the sweep was made to be a wavy line, to simplify measuring the range of the target (in the case shown, the range was 30 km).

8.3 Involvement of Industry

According to [5], having received the message about the outcome of the tests, Joffe tried in every possible way to speed up the difficult issue of bringing the radio industry to radio-detection system design and production. The path from laboratory setup to industrial design (and even the

Figure 32. S. P. Rabinovich.

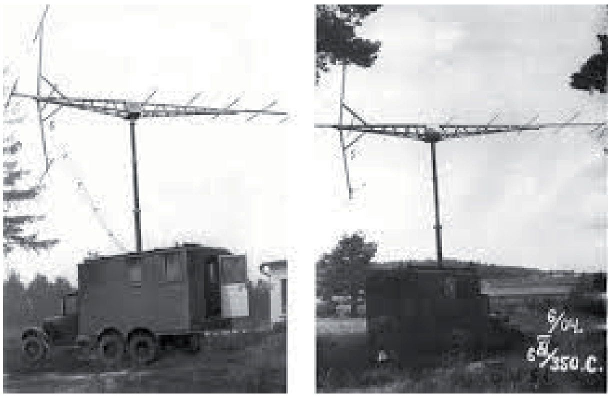


Figure 33. The two-antenna radio-detection system “Redut.”

transportable system, as was required by NIIIS) was not easy. The radio plant did not give up taking on this task, but they set an unacceptable cost for the first prototype and for the duration of its manufacture. Therefore, NIIIS decided to make a transportable prototype on their own, using the existing equipment of LIPT. They nevertheless continued the search for a contractor from industry. Finally, an acceptable contractor was found (the R&D Institute of Radio-Industry). In April 1939, the Defense Committee of the Government made a decision about the development (with the participation of employees of LIPT) of two sets of transportable stations for the radio detection of airplanes. The work was headed by A. B. Slepushkin (Figure 31). L.V. Leonov was engaged in transmitter development, S. P. Rabinovich (Figure 32) in the oscilloscope indicator, and V. V. Tikhomirov (1912-1985) in the receiver.

As a result of these efforts, in 1939, the NIIIS created a prototype with two antennas. It was named “Redut” (Figure 33). The units and other equipment of LIPT were used in the Redut system. It was a transportable prototype, consisting of two automotive vans with the equipment inside, and antennas on the roofs. This made it possible to conduct comprehensive testing of the system, in particular, to determine the dependence of the range of its functioning on the height of the airplane. The testing was held in the autumn of 1939, in the region of Sebastopol, Crimea. Kobzarev took part in those tests. During the tests, it was demonstrated that an aircraft located at 150 km from the Redut was detected. It became clear that exactly this detection range (150 km) was reasonable as a requirement for future industrial sets. Shortly after the Redut was tested in Sebastopol, the USSR started the war against Finland. Because of this, at the initiative of A. Joffe, the Redut prototype was installed on the Karelian Isthmus, and during the war it was used in military operations.

At the beginning of 1940, two operational systems were manufactured by the R&D Institute of Radio-Industry. The system consisted of two cabins spaced by 300 m, which could synchronously rotate (Figure 34). One of the cabins had a transmitter installed in inside, and the other one carried the receiver. A more-detailed description was given in [2]. The composition of each system (station) included:

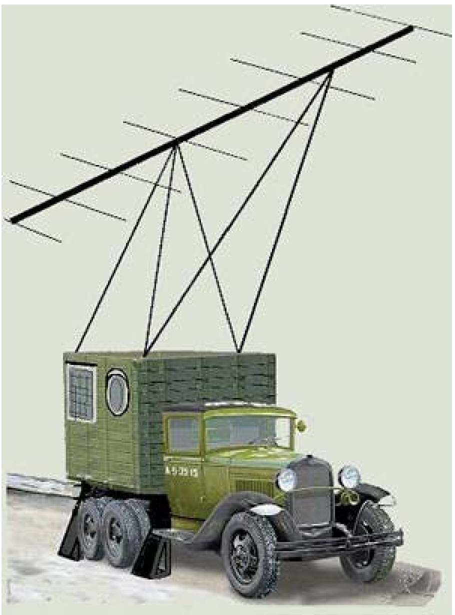


Figure 34. The Redut system, with rotating cabin.

- A generator (50 kW at a wavelength of 4 m) mounted inside the cabin, which rotated on the chassis of a ZIS-6 truck.
- Receiving equipment and a display with a sweep on the CRT screen with a length of 150 mm to 180 mm, designed for a detection range of 100 km, in the similarly rotating cabin on the second car, a GAZ-3A truck.
- Two Yagi antennas, rigidly reinforced at each of the cabins with synchronous rotation. The antenna had five directors, one active dipole, and a reflector.
- A power unit of 30 kW to 40 kW power, mounted on the GAZ-3A car (the third car of the station).

In July 26, 1940 this “station” was put into service under the name “RUS-2.”

After the first two samples, ten more sets of the same station were fabricated. The operational work with them was extremely difficult, due to the continuous rotation of the cabin, and work on improving the station continued at a rapid pace. In particular, a high-frequency current collector was developed: a device that allowed the antenna to rotate while the equipment, located in the cabin, remained stationary (Figure 35). The modulation scheme was also improved.

8.4 Stationary Radar System

During the USSR-Finland war (the Winter War), it was decided to build a large fixed radar system in front of Leningrad, with increased operating range, for the air defense. The construction of this system was carried out extremely rapidly. The radar system consisted of two 20 m towers, separated by 100 m, on the bank of the lake. The towers were booths, with antennas on the roofs. One

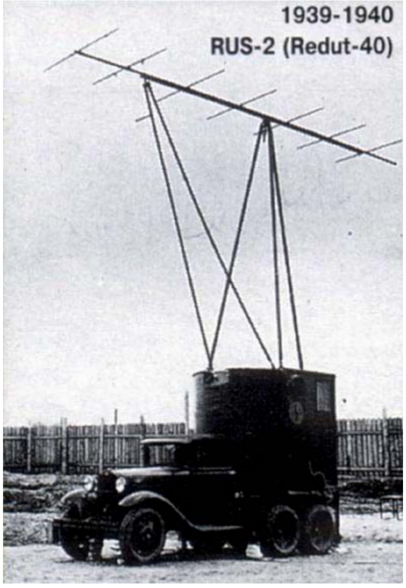


Figure 35. The modified RUS-2 radar station.

booth housed the generator, while the other booth housed a receiving device and oscilloscope. The antennas were connected by a steel cable, and could be synchronously rotated within a sector of 270°. A house with a room for the modulator, the control oscilloscope, and lounges for staff was built next to the tower with a generator.

After the Winter War, the stationary radar station was used by LIPT for further research. One of the works carried out at the station was testing under real conditions the ways proposed by P. Pogorelko to combine the transmitting and receiving antennas. Reception was conducted both on the transmitting antenna and on the "native" antenna in the receiving-antenna tower. The tests, carried out in July 1940, showed that the signal from the aircraft appeared and disappeared on both screens at the same time, which proved the possibility of creating a radar with a single antenna, with the same range.

Shortly before World War II came to the territory of the USSR (June 22, 1941), the government issued a decree, awarding the USSR State Prize (Stalin Prize) to a group of outstanding scientific works and inventions. The staff of the LIPT laboratory, who created the pulse radar system (Yu. Kobzarev, P. Pogorelko, and N. Chernetsov) were among the awardees. In his memoir, Kobzarev noted: "It is regrettable that the initiator of the work, P. K. Oschepkov, was not included into the team of awardees." He was already in the Gulag in that time.

9. Airborne Radar Systems

Another work of the R&D Institute of Radio-Industry, done in the pre-war and war years, also deserves to be commented on: the creation of the airborne radar, providing the possibility of guidance to fighters at night. Moreover, radar stations for detection of aircraft from ships of the Navy were developed and found wide application, but will not discussed be discussed in this paper.

The idea of using radar in fighter aircraft appeared in 1939. This question was debated in the Research Institute of Air Force in 1939-1940. Once upon a time, in 1939, observing the operation of the Redut radar during the war with Finland, the chief of the group of the special services department of the Air Force Institute, General S. A. Danilin, conceived the idea of using radar principles onboard of night combat aircraft. Danilin discussed it with the leading engineers of his departments. The panelists proposed various ideas for creating devices for night combat. Some proposed to use infrared equipment, others proposed acoustic equipment with a piezo-crystal receiver, while a third (engineer E. S. Shtein) suggested the use of radio detection. Danilin warmly supported the last proposal, which called for the creation of equipment similar to Redut. It was this ground-based station that became a prototype of an onboard radio detection device for the Air Force [42].

The goal was to identify fighter-bombers at night and under cloud conditions to create a means of night fighting. Initially, the frequency band of 15 cm to 16 cm was proposed, based on a klystron transmitter in pulsed mode [43]. The difficulty was in placing the equipment on the aircraft, as the mass of this equipment in those years (together with power supplies) reached 500 kg. Another problem was the combination of simultaneous control of the aircraft and radar system. In practice, a fighter pilot could not simultaneously fly a plane, search (with radar) for the enemy, and fire upon the enemy.

It was decided to install radars not on a single-pilot aircraft, but on the two-seater plane: the Pe-2 dive-bomber. The team of designers was led by V. V. Tikhomirov (Figure 36), and included R. S. Budanov, A. A. Fin, A. R. Volpert (1908-1988), and I. I. Volman (all from RDI Radio-

Figure 36. V. V. Tikhomirov.

Industry). Initial tactical and technical requirements for the first onboard radar at that time were pretty primitive:

- Detection range (by plane): 4 km to 5 km
- Zone of detection in azimuth: 120°
- Detection zone in elevation angle: 45°

9.1 Gneiss

According to these requirements, a mock-board radar, "Gneiss-1," was created. Due to a lack of the necessary klystrons, meter waves were subsequently used. The new version was called "Gneiss-2" (Figure 37). It was officially taken into service in 1943, but they really started using these radars even earlier, in 1942, at Stalingrad. The principal parameters of Gneiss-2 were :

- Carrier frequency: 200 MHz
- PRF: 900 Hz
- Pulse duration: 2 μs to 2.5 μs
- Max range: 3.5 km
- Pulse power: 10 kW
- Azimuth error: ±5°

The next airborne radar developed was "Gneiss-5" (1944). The maximum range of airplane detection was 7 km. It was a step forward: it used new devices and had higher reliability. In 1945, airborne radars were also commissioned to detect surface ships, and these were developed based on Gneiss: "Gneiss-2M" and "Gneiss-5M." They used the new antennas that allowed detecting both air and surface targets. The range of "Gneiss-5M" on ships was 10.5 km to 36 km, depending on the tonnage of the ship, and the coast-detection range was 60 km.

At the end of the war, the first panoramic radar was created. It was designed as a radar bombing sight, and also for navigation purposes. These radars became the prototypes for the navigation radar of civil aviation: RLV-DL, BPR-4G, ROS-1. These were followed by the airborne radar of the second generation, the meteorological and navigation radars. The first of these was "Groza" (Thunderstorm), developed in Leningrad in the early 1960s. For many years, it was produced in Kiev at the "Communist" plant. The development of new weather radars and their production was subsequently fully transferred to Kiev, where the new family of "Groza-M" radars was created. The next step was the development of radars with digital signal processing and color television images, the first of which was MNRLS-85, established in Kiev (the chief designer of which was Volodymyr Belkin).

10. Identification Friend or Foe

All radio-detection systems mentioned above were in fact autonomous primary radars. The history of secondary radars (i.e., systems consisting of interrogators and transponders) also began during World War II. After solving the problem of long-range detection of aircraft and equipping air defense with radars, an additional task emerged. Not only was detection of an aircraft important, it was also necessary to determine the identity of the detected airplane: either "friend or foe."

In May 1940, DC-RA and LIPT signed a contract for the development of the airplane responder, which had to work with the ground-based radar "Redut." Kobzarev recovered the stationary radar that was built on the outskirts of Leningrad, to be used by LIPT for further research. In particular, the experiments were carried out to establish a system for recognition of own aircraft. Based on the study of the scattering of radio waves by planes and estimates of the radar cross section, it was supposed that by placing a half-wave dipole on the airplane, and connecting it at the middle in a pre-determined order, one could cause a change in the magnitude of the reflected signal in the same order. Experiments carried out to implement the idea of such a "passive identification device" failed.

A group of experts of LIPT – N. Alekseyev, D. Malyarov, and Yu. Korovin, reinforced by S. Braude from UIPT (Kharkiv) – then [2] developed an "active responder." This was, a device that generated and emitted a pulse in response to the sounding waveform that came to the airplane equipped with such an active responder. It was a kind of a regenerative receiver. This device was successfully tested in the last pre-war days.

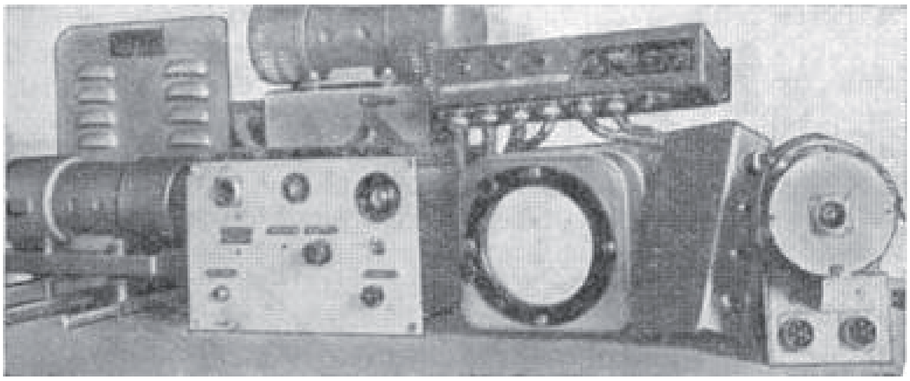


Figure 37. The complete set of Gneiss-2.

In 1942, the contract was signed with one of the radio-industry factories, and mass production of "friend or foe" devices began in 1943. This was an example of a very tight schedule for the development and batch production of airborne radio-electronic equipment.

The principle of this identification was the fact that an impulse, visible on the screen of a ground-based display near the reflected radar signal, was supplied as a recognition signal. That is, own airplanes equipped with the responder were displayed as a dual mark. The weight of such a device was 3.5 kg, the power consumption was up to 100 W, and the wavelength was 4 m to 4.3 m.

Such responders could be considered the prototypes of modern aircraft transponders, widely used in air traffic control (ATC) systems. These allow the air traffic controller to automatically receive additional information about aircraft that are in the service area.

11. Compression of RF Wideband Pulses

11.1 Establishment of ARTA

After the war, in 1946, the Artillery Radio-Technical Academy (ARTA) was established in Kharkiv. It later became the most powerful radar school in the Soviet Union. One of the most important tasks in the early years of pulse radar was the problem of clutter elimination. The principle of moving-target indication (MTI) with a delay-line canceller was already known. At the end of the 1940s, Yakov D. Shirman (1919-2019) (Figure 38), then a young teacher at ARTA, tried to more deeply understand the issues of MTI in his lectures for the students [44]. This perhaps helped him suggest the transition from a single delay-line canceller to double- and multiple-delay-line cancellers. In 1951, he obtained patent No. 13855, USSR, Ministry of Defense (Figure 39) on an MTI system with a multiple-delay-line canceller. The effectiveness of the MTI system was significantly improved. This invention was very quickly implemented in the P-12 radar system, and a little later, in the anti-missile system C-75, and in many other radars [44, 45].

Figure 38. Yakov D. Shirman (circa 1950).

Министерство Обороны Союза ССР
(министерство или ведомство)

АВТОРСКОЕ СВИДЕТЕЛЬСТВО
№ 13855

Настоящее авторское свидетельство выдано
гр. ШИРМАНУ Якову Давыдовичу

на изобретение "СФ"

в соответствии с приложенным описанием по заявке № 12836/ 42903
с приоритетом от 31 декабря 1951г.

Заместитель министра
Маршал Советского Союза Жуков (Жуков)

Зарегистрировано в Государственном реестре изобретений Союза ССР 4 декабря 1953 г.

Действие авторского свидетельства распространяется на всю территорию Союза ССР.

Начальник Патентного отдела
Управления по стандартизации
при ~~Совете Министров~~ Союза ССР
Госплане

Москва, 8 декабря 1953 г.

Московская печатная ф-ка „Гознак". 1951. Зак. 5815.

Figure 39. Patent No. 13855 (Ministry of Defense, 1951).

11.2 The Problem of Improving Range Resolution

A contradiction arose between the tasks of increasing the range of operation and the range resolution. This seemed very serious in the 1950s. At that time, rectangular RF pulses without intra-pulse modulation were used in pulse radars. To increase the range of the radar it was necessary to increase the energy of the sounding pulse. To do this, the pulse duration had to be increased, the peak power always being limited. In turn, increasing the duration of such an RF pulse led to a degradation of the range resolution: both a theoretical and a practical problem. Ya. Shirman proposed two solutions in 1955 [46, 47] as simple approaches to increasing range resolution in a secondary receiving channel. In both cases, a long RF pulse was converted with the help of linear circuits into two short pulses. In addition, a pair of long pulses was converted , according to the superposition principle into two pairs of non-overlapping short pulses that were actually wideband. It was a radar with a two-channel receiver, where one channel was for long range, and a secondary channel was for high resolution. This approach was confirmed by laboratory and live experiments [45]. However, the thought that then appeared in the scientist's mind was that perhaps it would be better to directly radiate wideband sounding pulses, in order to simultaneously solve both tasks with the help of a single matched receiving channel: to reach increasing resolution without loss in range. Simultaneously, a theoretical problem was important: how to modernize the Woodward theory of time-frequency resolution in order to cover the described results of time super-resolution? It was really important to understand this matter, because it could open up the opportunity to also assess the prospects of angular super-resolution.

Yakov D. Shirman was an ambitious scientist, but also a very modest and extremely honest person. He also paid attention to the history of radar. In his papers and personal conversations, he indicated some predecessors whose lectures, talks, or work contained some ideas that could be related to his achievements. He personally prepared and supervised 20 Doctors of Science and 45 PhD holders in radar-related fields. He created an exclusively strong team of researchers. Of course, his pupils made great contributions to developing his research and development work. Unfortunately, it is impossible to mention many names in this paper. However, the paper written by Shirman himself, together with his pupils [45], contained a lot of references.

11.3 Compression of RF Wideband Pulses

Single-channel matched filtering was first proposed by Ya. D. Shirman for random phase-shift-keyed signals in 1955 [45]. He then developed it for deterministic linear frequency-modulated (LFM) signals in July 1956 [48]. The latter invention described a method of increasing radar range resolution using frequency-modulated sounding pulses, and the device to implement this method. In the device, to compress the duration of receiving (reflected) pulses, the receiver included a compression filter (for example) at intermediate frequency. This filter was implemented as a tapped delay line with continuous or discrete tapping, and capacitive, inductive, or conductive coupling with the delay line. In 1956, the principle of compression of linear frequency-modulated pulses was checked in the experiment done by Shirman's pupils, B. V. Naydenov, V. N. Manzhos, and Z. A. Vainoris. They designed a matched filter based on a spiral delay line. It was implemented as a dielectric rod, and located in a glass tube. Discrete capacitive pickups were arranged. The distances between them were different. They were proportional to the changing semi-period of the pulse-response characteristics (Figure 40)

The initial FM pulse, with a duration $\tau = 5$ µs and a frequency deviation of 4 MHz (±2 MHz) at a mean frequency of 3 MHz, was applied to the input of such a matched filter (MF). At the output of the matched filter, the pulse was compressed six to 10 times in time, as was clearly seen from the oscillograms. However, it had the level of remaining (sidelobes) considerably higher than the calculation, due to the absence of careful coordination of the filter's pulse response with the signal's shape.

The results were discussed with leading experts and caused great interest. Despite the doubts of some of the experts, this approach immediately received intensive development.

In the summer of 1959, based on the P-12 Radar System, the prototype of the VHF-band radar with linear-frequency-modulated pulse compression was created and tested in the modes of aircraft and missile detection, under the leadership of Ya. D. Shirman (Figure 41). The sounding pulse duration was 6 µs at a spectrum width of 5 MHz. After processing, the pulse duration was decreased 30 times and the range resolution was correspondingly improved, without a practical decrease in the range of operation. At the end of 1959, on the same basis, a new version of the radar prototype was created, with a pulse duration of 100 µs at the same average pulse power. As a result of the coherent processing of the received signal, the range of operation was increased two times, while maintaining the same range resolution [44, 45].

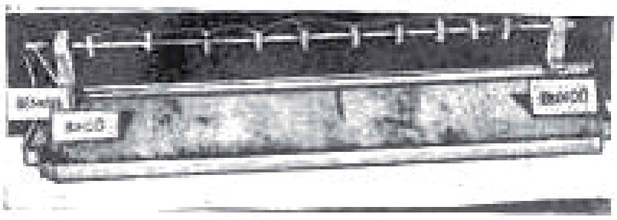


Figure 40a. The matched filter.

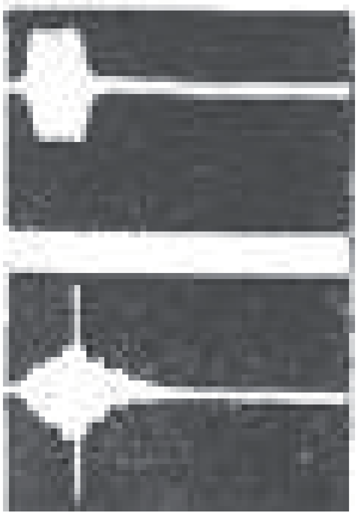


Figure 40b. The result of the pulse compression in 1956.

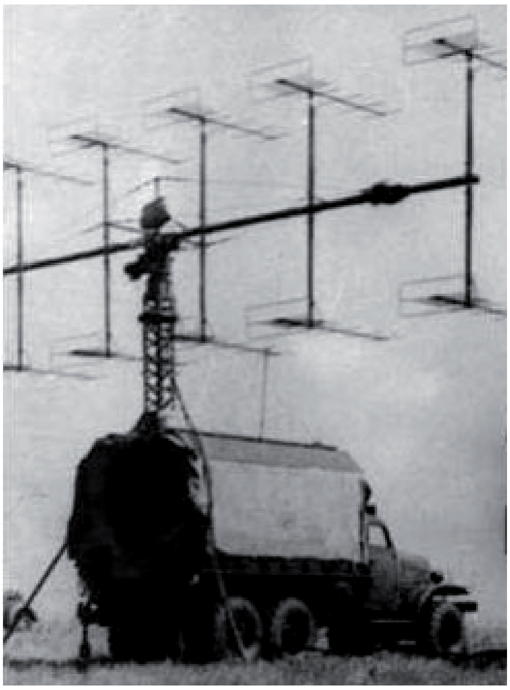


Figure 41. The P-12 radar system, where the first pulse compression was implemented.

The theory of pulse-compression filters with discrete irregular tapping was later described in a book [49]. It was developed based on the theory of pulse communications published much earlier by Shirman (1946). Compression filters were practically implemented using electrical (V. N. Manzhos, Yu. A. Koval, N. M. Ivakhnenko) or ultrasonic (V. V. Trubnikov) delay lines. The phenomenon of dispersion in delay lines was used; weighted processing was applied to minimize the sidelobe level of compressed pulses. Compression filters were also developed and built for processing phase-shift-keyed impulse signals.

The invention of wideband-pulse compression by matched filtering was one of the most significant contributions to radar theory and technique after WW II. It was independently done in Ukraine (then a part of the USSR), and practically at the same time as in the USA (Charles Cook, 1955, published in 1968 [50]). Shirman did it in a much more sophisticated and effective way.

Figure 42a. D. Tsursky and V. Almazov, together with Ya. Shirman (in the middle), shown tuning the compressing filter.

11.4 The First Super-Wideband Radar

Widening the bandwidth of the sounding waveform up to 100 times relative to then-existing radar systems made it possible to significantly improve both the range resolution and the accuracy of range measurement with matched signal processing. The first full-scale live experiment of the surveillance of aircraft with a super-wideband linear-frequency-modulated-pulse radar were made during 1962-64, using the S-band radar PRV-10 [32, 44]. A unique (for those times) compression filter for linear-frequency-modulated pulses of 2 μs at a bandwidth of 72 MHz, based on a coaxial cable, was developed by V. B. Almazov and D. A. Tsursky, who were students of Prof. Shirman (Figure 42).

Experiments with such a radar showed a range of airplane detection up to 110 km. An actual range resolution in the automatic lock-in mode of 3.0 m to 4.5 m at 65 km. This provided resolution even of elements of a target in the air, and observation of the range image (profile) of a target.

The Pioneer Award Committee of the IEEE Aerospace and Electronic Systems Society named Yakov D. Shirman as the recipient of the Pioneer Award, with the following citation: "For the independent discovery of matched filtering, adaptive filtering, and high-resolution pulse compression for an entire generation of Russian and Ukrainian radars." Formal presentation was made at the International Radar Conference, Bordeaux, France on October 2009. Six months later, Yakov Shirman passed away in the 91st year of his life.

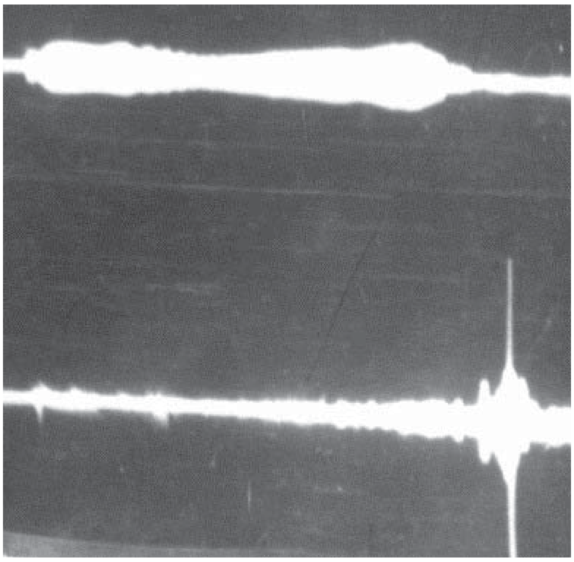


Figure 42b. The compression ratio was 144 in 1961.

12. Conclusions

In spite of the very fair general opinion of science as an international field of human activity, the development of modern radar in different countries was independent, and covered by a curtain of secrecy, because of obvious military applications.

Soviet radar achievements were disclosed later than those in western countries. Inside the USSR, the achievements in the R&D field obtained in Ukrainian institutions were never considered as such, because it was a single state, while in sports and culture there were quite official parades and competitions between the "Socialist Republics." This paper has clarified the valuable contributions of Soviet and Ukrainian engineers and scientists to the early developments in the field of radio detection, or radar. These contributions were really significant and independent, and many aspects of the radio detection of airplanes were developed at least not later than in other countries. The complicated history of microwave and radar technology in the Soviet Union – in particular, of the significant Ukrainian contribution – was a good basis for the modern scientific and technological achievements [51, 52].

13. Acknowledgment

The author is very grateful to Profs. Alexander I. Nosich and David I. Lekhovitskyi for numerous discussions of various issues of the complicated history of radar.

14. References

1. P. K. Oshchepkov, *Zhizn i Mechta* [*Life and Dream*], Moscow, Moskovskiy Rabochiy Press, 1967 (in Russian).

2. M. M. Lobanov, *Nachalo Sovetskoy Radiolokatsii* [*Beginning of Soviet Radar*], 1975 (in Russian).

3. F. J. Yanovsky, "Radar Development in Ukraine," International Radar Symposium IRS-2014, Gdansk, Poland, June 16-18, 2014, pp. 61-66.

4. Dogovor GAU-CRL [Contract between PDA and CRL], #164 NTO, October 23, 1933, TSGASA, F-20, op. 40, ed. hr 70, leaf 72-146 (in Russian).

5. Yu. B. Kobzarev, "Perviye Shagi Sovetskoy Radiolokatsii" ["First Steps of Soviet Radar"], *Priroda*, No. 12, 1985, available at http://vivovoco.astronet.ru/VV/JOURNAL/NATURE/OLD/RADAR.HTM (in Russian).

6. *Nauchno-Technicheskiy Zhurnal GAU* [*Scientific and Engineering Journal of PDA*], 1934, TSGASA, F-20, op.41, ed. hr.70, leaf 72-146 (in Russian).

7. P. K. Oshchepkov, "Modern Problems of Development of Engineering for Air Defense, Collected Articles of Air Defense (Sbornik PVO)," 1934, No. 2 (in Russian).

8. *Arkhiv NIIIS KA* [*Archive of RDTIC-RA*], 1934, number 7/40, 1934, No. 7/40 (in Russian).

9. B. K. Shembel, *U Istokov Radiolokatsii v SSSR* [*At the Sources of Radar in USSR*], Moscow, Sovetskoe Radio, 1977, 82 pp. (in Russian).

10. A. I. Nosich, A. A. Kostenko, and V. M. Yakovenko, "Radio-Physical Researches in Ukraine," *Radio-Physics and Radio-Astronomy*, **9**, 1, 2004, pp. 81-106 (in Russian).

11. A. A. Kostenko, A. I. Nosich, and I. A. Tishchenko, "Development of the First Soviet Three-Coordinate L-Band Pulsed Radar in Kharkiv Before WW II," *IEEE Antennas and Propagation Magazine*, **43**, 3, June 2001, pp. 29-48.

12. Y. A. Khramov, *History of Formation and Development of Physical Schools in Ukraine*, Kiev, Feniks, 1991 (in Russian).

13. Yu. B. Kobzarev, L. A. Sena, and V. M. Tuchkevich, "Dmitry Apollinaryevich Rozhansky," *Uspekchi Fizicheskikch Nauk* [*Advances in Physics Sciences*], **138**, 4, 1982, pp. 675-678 (in Russian).

14. V. Y. Frenkel (ed.), *Fiziki o Sebe* [*Physicists about Themselves*], Leningrad, Nauka, 1990 (in Russian).

15. Interview of S. Braude, November, 1998, recorded by A. Kostenko (in Russian).

16. V. G. Bartenev, G. Yu. Kobzarev, "Dmitry Apollinaryevich Rozhansky – Prominent Scientist – Radiophysicist," *Electrosvyaz: Istoriya i Sovremennost* [Communications: History and Contemporaneity], No. 2, 2014, available at http://www.computer-museum.ru/articles/?article=336 and [http://museum-dom.ru/bio05/kobzarev-ab.html (in Russian).

17. A. A. Abrikosov, *Academician L. D. Landau, Brief Biography and Review of Publications*, Moscow, Nauka, 1965 (in Russian).

18. A. I. Nosich and A. A. Kostenko, "In the Labor People's Name: Development of 60-kW Magnetrons in the Artificial Famine Plagued Ukraine in the Early 1930's," Proc. Int. Conf. Origin and Evolution of the Cavity Magnetron (CAVMAG-2010), Bournemouth, 2010, pp. 82-88.

19. A. W. Hull, "The Effect of a Uniform Magnetic Field on the Motion of Electrons Between Coaxial Cylinders," *Physical Review*, **18**, 1921, pp. 31-57.

20. A. W. Hull, "The Magnetron," *AZEE Journal*, **49**, 9, pp. 715-723, 1921.

21. A. Zachek, “Uber Eine Methode zur Erzeugung von Sehr Ihrzen Elektromagnetschen Wellen,” *Casopis pro Pest. Math. a Fyz (Prague)*, **53**, 1924, p. 378.

22. E. Habann, “Eine Neue Generatore,” *Zeitshrift fur Hochfrequentztechnik*, **24**, 1924, pp. 115-120.

23. A. A. Slutskin and D. S. Shteinberg, “Obtaining the Oscillations in Cathode Tubes with the Aid of Magnetic Field,” *Zhurnal Russkogo Fiziko-Khimicheskogo Obshchestva* [*Journal of Russian Physics and Chemical Society*], **58**, 2, 1926, pp. 395-407 (in Russian).

24. A. A. Slutskin and D. S. Shteinberg, “Electronic Oscillations in Two-Electrode Tubes,” *Ukrainski Fizychni Zapysky* [*Ukrainian Journal of Physics*], **1**, 2, 1927, pp. 22-27 (in Ukrainian).

25. V. K. Tkach, “Abram A. Slutskin,” Proc. Physics Dept. of School of Physics and Mathematics of KhSU, No. 4, pp. 17-22, 1953 (in Russian).

26. Y. V. Pavlenko, Y. N. Ranyuk, and Y. A. Khramov, *Delo UFTI* [*The Case of UIPT*], Kiev, Feniks, 1998 (in Russian).

27. TsGAOR [The October Revolution Central State Archive], Fond 166, opis 2, delo 1212, pp. 5454-559 (in Russian).

28. H. Yagi, “Beam Transmission of Ultra-Short Waves,” *Proceedings of the IRE*, **16**, 6, 1928, pp. 715-741.

29. K. Okabe, “On the Short-Wave Limit of Magnetron Oscillations,” *Proceedings of the IRE*, **17**, 4, 1929, pp. 652-659.

30. A. A. Slutskin, S. Y. Braude, and I. D. Truten, “Obtaining High-Power Oscillations of the dm-Band in Continuous-Wave Magnetrons,” *Radiotelchnika*, **1**, 9, 1946, pp. 12-17 (in Russian).

31. P. P. Leljakow, A. J. Usikow, I. A. Wyschinsky, “Intermittent Oscillations in the Split-Anode Magnetron,” *Physicalische Zeitschrift der Sowjetunion*, **10**, 2, 1936, pp. 266-268.

32. F. J. Yanovsky, “On the Ukrainian Contribution to Radar,” European Radar Conference, EuRAD-2014, Rome, Italy, October 8-10, 2014, pp. 41-44.

33. Interview of A. Usikov, January, 1994, recorded by V. Lapty (in Russian).

34. A. Y. Usikov, Draft Memo on “Zenit” and “Rubin” Radars, IRE Archive, Kharkiv, circa 1944 (in Russian).

35. Y. N. Ranyuk, “L. D. Landau, and L. M. Pyatigorsky,” *Voprosy istorii Estestvoznaniya i Tekhniki* [*Problems of History of Science and Technology*], No. 4, 1999, pp. 80-91 (in Russian).

36. V. P. Vizgin, “‘Nuclear Shield’ in Russian Physicists’ ‘Thirty-Year War’ Against Incompetent Criticism of Modem Theories,” *Uspekhi Fizicheskikh Nauk* [*Advances in Physics Sciences*], **169**, 12, 1999, pp. 1363-1389 (in Russian).

37. Yu. I. Krivonosov, “Landau and Sakharov in the KGB Files,” *Voprosy istorii Estestvoznaniya i Tekhniki* [*Problems of History of Science and Technology*], No. 3, 1993, pp. 123-132 (in Russian).

38. A.Y. Usikov, “Works in Radio-Engineering, Radio-Physics, Electronics and Communications in Ukraine in the Past 60 Years,” *Radiotelchnika (Kharkiv)*, No. 12, 1982, pp. 5-14 (in Russian).

39. H. S. Booker and W. Walkinshow, “The Mode Theory of Tropospheric Refraction and its Relation to Waveguides and Diffraction,” in *Meteorological Factors in Radio-Waive Propagation*, London, Physical Society and Royal Meteorological Society, 1946, pp. 80-127.

40. A. Schneider, “Oversea Radar Propagation Within a Surface Duct,” *IEEE Transactions on Antennas and Propagation*, **AP-17**, 2, 1969, pp. 254-255.

41. W. E. Gordon, “A Hundred Years of Radio Propagation,” *IEEE Transactions on Antennas and Propagation*, **AP-33**, 2, 1985, pp. 126- 129.

42. Sergey Ivanov, “The Russian Engineering,” July 2006 – January 2007 – November 2007, available at http://www.russianengineering.narod.ru/tank/russradar.htm (in Russian).

43. F. J. Yanovsky, *Radiolokatsiyni Systemy Povitryanykh Suden* [*Radar Systems of Aircraft*], Kiev, Textbook Technical Universities, NAU press, 2012 (in Ukrainian).

44. “History of Radar Department in ARTA,” available at http://arta46.narod.ru/history/torl/torl1.htm (in Ukrainian).

45. Ya. D. Shirman, V. N. Manzhos, and D. I. Lekhovytskiy, “Some Stages of Development and the Problems of the Theory and Technology of Radar Signals Resolution,” *Radiotechnika*, No. 1, 1997, pp. 31-43 (in Russian).

46. Yakov D. Shirman, “Pulse Radar,” Patent No. 152487, Priority date: November 21, 1955, Publication date: January 1, 1963 (in Russian).

47. Yakov D. Shirman, “Device for Selection of Impulse Signals,” Patent No. 149134, Priority date: December 24, 1955, Publication date: January 1, 1962 (in Russian).

48. Yakov D. Shirman, “Method for Improving the Resolution of the Radar and the Device for its Implementation,” Patent No. 146803, Priority date: July 25, 1956, Publication date: January 1, 1962 (in Russian).

49. Ya. D. Shirman, *Razreshenie i Szhatie Signalov* (*Resolution and Compression of Signals*), Sovetskoe Radio, 1974 (in Russian).

50. Charles E. Cook, "Pulse Stretching and Compression Radar System, US Patent No. 3400396A, Priority date: November 14, 1955, Publication date: September 3, 1968.

51. A. I. Nosich, Y. M. Poplavko, D. M. Vavriv, and F. J. Yanovsky, "Microwaves in Ukraine," *IEEE Microwave Magazine*, December, 2002, pp. 82-90.

52. F. J. Yanovsky, "Modern Radar Systems in Ukraine," International Radar Symposium (IRS-2015), Dresden, Germany, 2015, pp. 990-997.

53. F. M. Andreev, *Karazintsy – Rodonachalniki Impulsnoi Radiolokatsiynoi Tekhniki* [*Karazin University Scientists Who Were Fathers of Impulse Radar Engineering*], Kharkiv, Karazin KhSU press, 2014, ISBN 978-966-285-099-4 (in Ukrainian).

54. *Bolshaya Sovetskaya Entsiklopedia* [*Great Soviet Encyclopedia*], **10**, p. 1155, Ioffe (in Russian).

Introducing the Author

Felix Yanovsky is a Professor and has been with the National Aviation University, Kiev, Ukraine, since 1969. He currently serves as the Head of the Electronics Department. He was a guest professor at TU-Delft, The Netherlands (1996-1998, 2002-2003, 2014-2015); Penn State, USA (1998); TUHH, Hamburg, Germany (2005); Al-Balqa Applied University/Al-Huson University College, Jordan (2007); Hanyang University, Seoul, Korea (2008); WUT, Poland (2010, 2013, 2014); and Sunchon National University of Korea (2015). He was involved in airborne radar systems design with the R&D Institute "Buran" in Ukraine. He has given lecture courses in English on "The Theory of Radar," "Airborne Surveillance Systems," "Aerospace Land Survey and Remote Sensing," "CNS Systems," and others. He is the author or coauthor of more than 500 publications, 10 books and book chapters, and 41 invention patents. He was the Ukraine State Prize winner in the field of science and technology. He has supervised 10 PhD scientists and 250 MS engineers. He has participated in the organization of numerous international conferences. He was a founder of the Ukraine IEEE SP/AES Chapter, and was elected the IEEE Ukraine Section Chair for 2016-2017. He is a Fellow of the IEEE.

On the Development of Radar in South Africa and Its Use in the Second World War

B. A. Austin

Dept. of Electrical Engineering and Electronics
University of Liverpool
Brownlow Hill, Liverpool L69 3GJ, UK (retired)
E-mail: abkaustin@aol.com

Abstract

The first radar echo was received in South Africa on December 16, 1939. The apparatus used in that first trial was designed at the University of Witwatersrand in Johannesburg, by a team led by Basil Schonland, Professor of Geophysics at the university, based on information supplied by Britain. With its designers soon in uniform as soldiers, the equipment operated in many theaters of war in Africa, the Sinai, and in Italy.

1. Introduction

South Africa declared war on Germany on December 6, 1939. It was a close-run thing, because the divisions within parliament were stark. The Nationalists favored neutrality, with some even openly sympathetic to Hitler. The Unionists, under Jan Smuts, a hero of the Boer War against Britain but a post-war anglophile dedicated to uniting his country's European peoples, rallied to the cause of supporting Britain in her hour of greatest need.

The country was ill-equipped to go to war. Not only were there serious divisions amongst the electorate, but the military forces had been allowed to run down to minimal levels during the 1930s, mainly (but not exclusively) as a result of the Great Depression. The army numbered fewer than 6000 regular soldiers. The air force had but a handful of military aircraft, while the naval service, of almost insignificant strength, was disbanded in 1934. Despite these shortcomings, South Africa's geographic position made her the guardian of the sea-route around the Cape. This was a region of major strategic importance, especially if the Suez Canal was to fall into German hands, or into those of its Axis allies in Europe, who were then positioning themselves.

In Britain, there was little doubt that support from their kith and kin within the Dominions of Australia, Canada, New Zealand, and South Africa would not only be forthcoming, but it would be crucial to the defense of the "mother country," even if only in terms of the manpower it could provide. This had been the case in the previous global conflict that had ended just twenty years before. Such an allied response to Nazi aggression was naturally expected again. As then, British military resources were spread thin in terms of resources, but their technical expertise was immediately made available to assist those key allies in their preparations for war. So it was that the government in London announced in February, 1939, at a secret conference of the High Commissioners of those Dominion countries, that [1]

> It has been found that wireless waves are reflected by aircraft in flight, and a technique of causing and measuring such echoes has been developed by means of which it is possible to determine the position and height of distant aircraft.

The disclosure went on to describe in some detail how this highly secret new technology, then known as RDF in England, could be used to provide early warning against attack from the air as well as well as defense against ship-borne actions by means of both coastal defensive radars as well as airborne equipment. South Africa's High Commissioner in London immediately communicated this information to his government. He also informed the responsible minister that Britain had offered to inform a "technical representative from the Dominion Governments" of the workings of the system, and therefore a suitably qualified physicist should be sent to London for a period of three to four months.

It was with this background information that South Africa became aware of what soon became known as radar, when Britain dispensed with the term RDF in favor of the concise and expressive name adopted in America in November 1940.

2. The RDF Secret

South Africa chose not to send a scientist to London, but rather sent a soldier, Brigadier General F. R. G. Hoare, the Director of Technical Services of the Union Defense Force (the UDF). He went to England to attend the technical briefings at Bawdsey Manor on the coast, near Ipswich. Bawdsey had become the home of British radar development shortly after the original discovery, made in February 1935, by Robert Watson-Watt and his colleague Arnold Wilkins, that radio waves from a suitable transmitter would be reflected with sufficient intensity by a metal-skinned aircraft such that they could be detected on the ground. This remarkable discovery – assumed in England for quite some time afterwards to be unique – has since become known as the Daventry experiment. It was named after the BBC transmitter at Daventry, which was used to transmit the signal that was reflected from a bomber aircraft of the RAF. Hoare was accompanied by an officer from the South African Air Force, a Major Willmott, who happened to be serving at that time in England. Needless to say, these two military men were soon out of their technical depth at Bawdsey. However, their visit was not in vain, because it enabled the British Air Ministry to establish what South Africa's defense needs might be around its very long and unprotected coastline, and especially at the country's major ports. Hoare immediately informed his Defense Headquarters (DHQ) in Pretoria that arrangements should be made to send a scientist to England.

As it transpired, the New Zealand scientist, Dr. Ernest Marsden, who was present at Bawdsey along with his scientific colleagues from Australia and Canada, was about to set sail for home. It was then realized that he could pass on to the South Africans all the technical information he had acquired whilst at Bawdsey, but that required a change of ship to one that would be calling at Cape Town. Marsden duly sailed on the *Winchester Castle* on September 2, 1939. Two weeks later, he met Basil Schonland, hastily dispatched to South Africa's mother city from his seat of learning in Johannesburg.

3. Enter Schonland

Basil Schonland (1896-1972) was a professor of geophysics at the University of the Witwatersrand, known as Wits, in Johannesburg. For much of the previous decade, he had established an international reputation as an expert on the physical processes involved in lightning discharges. By 1937, he had named most of them in the international literature. His terms such as the return stroke, the leader, the dart leader, and the pilot streamer were in common usage by lightning researchers elsewhere. The following year, he received Britain's highest scientific accolade when he was elected a Fellow of the Royal Society. Schonland's reputation as a physicist was therefore well established. Some had even dubbed him Benjamin Franklin's natural successor [2, p. 422] (Figure 1 is a photo of Schonland).

Figure 1. B. F. J. Schonland, the father of South African radar.

As well as photographing lightning with high-speed cameras, Schonland and his colleagues at the Bernard Price Institute of Geophysical Research (the BPI, as it was always known) at the university had also made considerable use of radio-based methods to delineate the details of the lightning process. Probably the most important of these techniques was radio direction finding. In this, a network of receivers tuned to some appropriate very low frequency where lightning emissions were most readily observable was used, with rotatable loop antennas to determine the direction of the lightning stroke. By means of triangulation among the various stations, the approximate position of the lightning strike was then fixed. This involved not only the design of suitable radio equipment, but, crucially, the use of the cathode-ray oscilloscope to display the lightning waveform. In doing this, Schonland followed the work pioneered in England by Watson-Watt and Edward Appleton at the Radio Research Station at Slough, near London.

The three men knew each other well. Appleton and Schonland had been research students together at the Cavendish Laboratory at Cambridge. Watson-Watt and Schonland first met at a conference of the British Association for the Advancement of Science, in London, in 1931. Schonland, who was born in Grahamstown, South Africa, and educated there at Rhodes University, spent the years of the First World War as a signals officer in the British army's Corps of Royal Engineers. He interrupted his post-graduate studies at the Cavendish in order to do so. It was during this time that he first met Appleton, a fellow signals officer and already a physicist of some repute. After obtaining his PhD at Cambridge in 1922, Schonland accepted an appointment as Senior Lecturer in Physics at the University of Cape Town.

Figure 2. Schonland, Hodges, and Phillips in Durban in 1939.

By 1937, he had come to the notice of many people, both at home and abroad. This was particularly true when his field of research changed from atomic physics, under Lord Rutherford in Cambridge, to the study of lightning in South Africa. The change came about because Cape Town was so far from the center of gravity of research on atomic physics that Schonland quite rightly felt that no meaningful progress could be made working entirely on his own, at the southern tip of Africa. He therefore looked for a new field, and found it in lightning. However, it was in Johannesburg, almost 1500 km from Cape Town, where lightning was really active during the summer months. It was there that Schonland made lightning research almost his own and particularly at the BPI, the institute that had been founded by its generous benefactor in order that Schonland could pursue his research there. It was with this background that South Africa's foremost physicist came to meet Dr. Marsden in Cape Town, in mid-September 1939, with both their countries now allied to Britain in the war against the Third Reich.

4.The RDF Manual

Schonland and Marsden traveled together on the next leg of Marsden's onward journey. The *Winchester Castle* docked in Durban harbor three days later. During that voyage, they locked themselves in the New Zealander's cabin while they studied in detail the *RDF Manual*, a copy of which had been given to each of the three Dominion scientists who had been briefed by Watson-Watt and his colleagues at Bawdsey. Immediately on their arrival in Durban, the two men made for the physics laboratory at Natal University College. The man in charge there was one of Schonland's former PhD students from the University of Cape Town, David Hodges, who was now actively participating with Schonland's team in Johannesburg in tracking lightning by radio. Hodges was assisted in this by an electrical engineer, Eric Phillips. Figure 2 shows Schonland, Hodges, and Phillips. There, after Schonland had sworn both Hodges and Phillips to secrecy – since they were soon to become party to details of Britain's greatest wartime secret, as solemnly communicated to them all by Marsden – the four men proceeded to make glass photographic slides of the pages of the top-secret manual. Once complete, the New Zealander returned to his ship for the journey home, while Schonland left immediately, by air, for Johannesburg.

5. Tracking Lightning

Tracking lightning storms across southern Africa by means of their radio emissions occupied Schonland's team throughout the years 1937 and 1938. Naturally, the longer the baseline of the direction-finding system, the better the accuracy. A second station was therefore set up in Hodges's laboratory in Durban, some 500 km from Johannesburg, on South Africa's east coast. There, Hodges and Phillips had constructed a DF system, based on the principles outlined by Schonland. In order to coordinate the task of identifying the source of a single lightning stroke from the multiplicity of such things at the height of a storm, careful coordination was required between the Johannesburg and Durban teams. This was made possible by means of a dedicated telephone circuit between the two cities, provided by the Postmaster General's office in Pretoria. The man who authorized this was the Under-Secretary for Telegraphs, Mr. Freddie Collins. He also served, in a part-time capacity, as the Assistant Director of Signals in the South African army. Lt. Col. Collins thus became a key player in the development of radio direction finding in South Africa. Along with all of those mentioned so far, he was to be part of the first South African venture into radar.

The two lightning-monitoring stations were given the identifying letters of JB, for Johannesburg, and D, for Durban. By this means, communications between the two, and especially the recording of key information, was considerably speeded up. However, soon those letters would take on a completely and far more significant meaning: JB would become the letters that designated South Africa's first radar.

Schonland reported to General Hoare and thereafter, word soon reached the South African Prime Minister, Gen. J. C. Smuts. Smuts was well aware of the secret briefings that had taken place in England following the visit to Bawdsey by Hoare and Willmott, just a short while before. Moreover, Smuts knew Schonland well. In fact, they were distantly related by marriage, and Smuts was also much interested in science, especially botany. The fact that Schonland's father was a renowned botanist at the university in Grahamstown meant that he and Smuts had occasional contact. This allowed South Africa's Prime Minister, now serving in that role for the second time, to keep a close eye on the career of the younger Schonland. Smuts had followed with interest Schonland's school days as something of a prodigy to his time as an undergraduate at university in Grahamstown, and from there to his doctoral studies under Rutherford in Cambridge. More recently, after

Schonland's great contributions to the study of lightning, it was Smuts who formally opened the new BPI building in Johannesburg, when it came into being in October 1938. It therefore followed that Smuts well knew when a South African physicist was needed to help his country join forces with its British and Dominion allies in the radar war, who that person should be.

Britain's initial intention, when releasing the information about RDF to its Dominions, was that they should become conversant with its operation, so that as soon as British equipment became available, they would be able to set it up and use it in the defense of their respective countries. However, the exigencies of war were such that British resources were stretched to their limits in simply meeting British needs. It was soon evident that no equipment would be forthcoming for the Dominions in the immediate future. As soon as Schonland realized this, he persuaded Smuts to allow him to go ahead with the development of a radar set that would at least enable South African forces likely to use the equipment to gain some useful practical experience. Smuts agreed.

6. Engineers to the Fore

Until now, the research carried out at the BPI had been the domain of physicists. However, Schonland immediately knew when he saw the details of the British Chain Home radar system – as described in the Marsden's *RDF Manual* – that he needed the assistance of electrical engineers with specific skills in the art of radio engineering to both effectively and quickly do the job. Intriguingly, this was not the thinking of Watson-Watt in England, when he embarked on the design of that original British RDF equipment. It was Watson-Watt's peculiar view that physicists without industrial experience should design the hardware [3, pp. 13-16]. What made this all the more surprising was the fact that Watson-Watt himself was an engineer!

Schonland immediately enlisted the support of three electrical engineers, all of whom were senior lecturers at their particular universities, and all who were well-versed in what to some was the black art of radio-frequency engineering Figure 3. From the University of the Witwatersrand, the home of the BPI, came G. R. Bozzoli, the son of Italian immigrants to South Africa, although he himself was born in Pretoria. Before becoming an academic at his alma mater, Bozzoli had been a broadcast engineer at the African Broadcasting Company, the predecessor of the South African Broadcasting Corporation. From Natal, Schonland asked for the services of W. E. Phillips, the same man who had assisted Hodges, Marsden, and himself to make the glass photographic slides of the *RDF Manual*. Phillips, as noted above, was also familiar with the direction-finding equipment used for tracking lightning activity. The third engineer to be recruited was N. H. Roberts from the University of Cape Town. Dr. P. G. Gane, who was Schonland's deputy at the BPI, was a physicist, but one who was particularly talented as a designer of circuits using thermionic valves (or tubes). Such expertise was then of considerable importance.

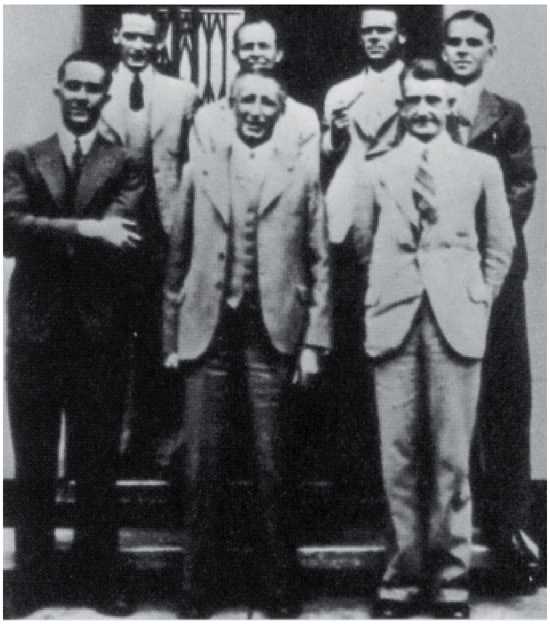


Figure 3. The radar design team at the BPI. (back) Keiller, Anderson, Gane, Hewitt; (front) Bozzoli, Schonland, Roberts.

The immediate problem that faced Schonland's team was the lack of suitable transmitting valves. South Africa was not at that stage producing any transmitting equipment: the broadcasting company of Bozzoli's immediate past imported all its equipment from England. What was more, careful study of the *RDF Manual* had suggested South Africa's radar needs would be best served by using the so-called searchlight principle. In this, the radar beam from the transmitting antenna would be regularly swept across a region of space and then received, preferably by using the same antenna when switched to the receiver. This was akin to the coastal defense (CD) radars then presently under development at Bawdsey. This was in contrast to the earlier Chain Home (CH) radar, which worked on the flood-lightning principle of "illuminating" a wide swath ahead of the transmitting antenna, and using a separate highly directional receiving antenna to determine a target's bearing. Technologically, the two systems were very different from one another. The searchlight system required a considerably higher radio frequency than the 20 MHz to 30 MHz (then called Mc/s) used by the CH radar. The higher frequency meant that the antenna size could be made small enough to be easily rotated, while still producing a beam of sufficiently narrow width. The British CD radars therefore operated at a frequency of about 200 MHz. That same frequency would also be used in the radar that evolved from this, intended specifically for the detection of low-flying aircraft, called the Chain Home Low, or CHL [4].

7. The Design Challenge

Bozzoli and his colleagues turned to the suppliers of radio equipment, and especially the components, used by the country's amateur-radio community. Along with their colleagues elsewhere in the world, South African "Hams" were keen (and competent) designers of much of their own equipment, particularly transmitters. In addition, they sought to operate at the highest frequencies available to the amateur-radio service. As a result, the dealers in such equipment in Johannesburg kept stocks of appropriate components. As discreetly as possible, the BPI placed orders for as many high-power transmitting valves capable of operating at the highest frequencies that the radio dealers could supply. The costs were all borne by a special account managed by DHQ in Pretoria, because by now the BPI had been officially handed over by the university to the UDF for the duration of the war. Lt. Col. Collins was now officially in charge, with Schonland reporting directly to him.

However, technical information was scarce, especially in South Africa. There were few engineering textbooks at that time that covered the design principles underlying high-power amplifiers intended for operation at frequencies much above 50 MHz in any detailed way. Other than the relevant pages of the *RDF Manual*, the two books that served the circuit designers well at the BPI were F. E. Terman's *Radio Engineering*, and the 1936 edition of *The Radio Amateur's Handbook*, published by the American Radio Relay League. There was also a dearth of suitable measurement and test equipment. They had no suitable signal generator, nor even an oscilloscope capable of making accurate measurements at frequencies above a few megahertz. Once again, they were in good company. Before moving to Bawdsey, Watson-Watt's team had set themselves up on a fairly isolated strip of land, almost completely surrounded by water, called Orfordness on the south-east coast of England. Over many years, it had been used by the Ministry of Defense for a variety of tests and experiments of a secret nature. It was therefore most appropriate to design Britain's early RDF equipment at such a remote place. However, the British scientists also suffered from a distinct shortage of suitable test gear. There was no signal generator, and all they had was a wavemeter, an old double-beam oscilloscope of doubtful bandwidth, and a multi-meter. In addition, they suffered at the hands of the hidebound and extremely cumbersome stores system operated by the military, which required forms to be filled out (always in triplicate) for even the most mundane of items [3, p. 12].

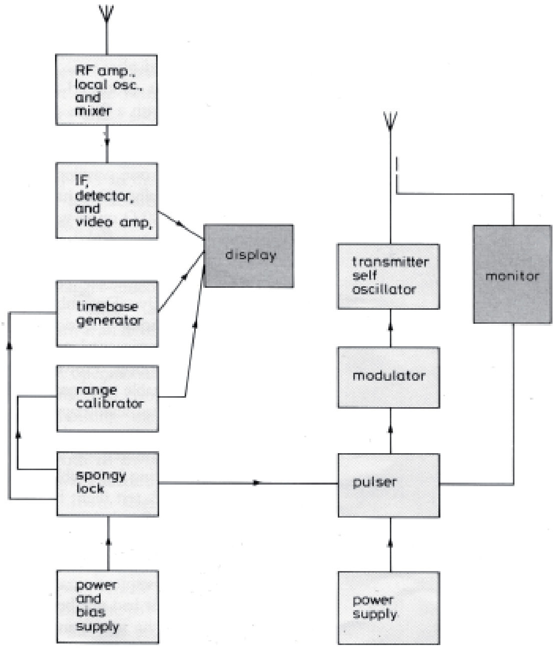


Figure 4. A block diagram of the JB radar system.

8. The JB0 Prototype

Schonland's team of three engineers and a physicist were assisted by J. A. Keiller. From its inception, the BPI had a well-equipped workshop, and Jock Keiller was the man who ran it. His part in the mechanical construction of South Africa's own radar equipment would be crucial. The design of the various elements of the radar transmitter, the receiver, the timing and display units, as well as the necessary power supplies, and the antenna, was decided by the team members themselves (Figure 4). Their objective was to produce a radar that would operate at the highest frequency they could achieve, given the limitations of the available transmitting valves. Each played to their particular strengths, with Bozzoli handling the RF, mixer, and local-oscillator stages of the receiver; Phillips took on the IF amplifier; Roberts looked after the timing and display circuits; while Gane handled the transmitter, and he would also design the antennas. In its prototype form, the first South African radar became known as the JB0. It would be classified today as a bistatic radar, because the transmitter and receiver had their own antennas, which could be separated from each other by some distance. Their rotation in synchronism was handled by a bicycle-chain arrangement, with the motive power provided by the legs of the radar operator.

Although all members of this very secret group of individuals then occupying the BPI were nominally still civilians, they soon fell under the jurisdiction of the South African Corps of Signals, and hence of Col. Collins. Nevertheless, Collins gave Schonland complete freedom to operate as he saw fit, while remaining as his interlocutor to the military high command, which obviously held sway over South Africa's slowly evolving war machine. However, it soon would be necessary to turn Schonland's men into soldiers of a sort, because it was they who would take their radars into the field of action. They naturally would become very much part of the military once there. Schonland himself made the transition into uniform very easily, since he had had experienced almost four years of soldiering during the First World War. For the others, it took some adjusting. Informally, they were known as the

Figure 5. A group photo of the SSS. Schonland is in the center of the front row, with Bozzoli on his left, and Roberts on his right. Second from the left in the back row is T. L. Wadley.

Special Wireless Section. Within time, as their numbers substantially increased, they became the Special Signals Services (SSS) of the South African Corps of Signals (SACS) (Figure 5).

By December 1939, the JB0 was complete and was ready for testing. This was quite remarkable, given that work on it had only commenced less than three months before. Its circuitry was conventional, except perhaps for Gane's transmitter. As far as they could be measured or estimated, the radar's characteristics were as follows. The transmitter operated at a wavelength between 3 m and 3.5 m (or about 86 MHz to 100 MHz). Its peak power output could only be estimated, but since the pulse width controlled by the modulator was initially about 20 μsec at a pulse repetition frequency (PRF) of 20 msec, it was about 30 dB greater than the average power developed by the two type 250 TH triodes used as a high-power pulsed oscillator. They were subsequently replaced by the type 354E triodes, which produced better performance. Their frequency of operation was determined by two short-circuited copper transmission lines, each nominally one-quarter wavelength long, which were the only tuned elements of that pulsed oscillator. Fine-tuning was accomplished by a small, widely spaced variable capacitor, associated with each line (Figure 6).

Bozzoli's radio-frequency sections of the receiver made use of the new "acorn" tubes, manufactured by RCA. These were claimed in the advertising literature as being suitable for ultra-high frequencies of 450 MHz, and even higher. He used the type 956 pentodes for both the RF amplifier and mixer, with the 955 triode as the local oscillator. The IF amplifier, designed by Phillips, followed the techniques used by the manufacturers of British television receivers at that time, while Roberts was much influenced by the ideas contained in the *RDF Manual*. His timing and control circuits included the "spongy lock" circuit that was used in Britain's CH radar system. Its purpose was to act as an electronic shock absorber to smooth out variations in the 50 Hz mains supply to which all the radars in the CH system were locked, thus ensuring that they all operated in synchronism. Such sophistication, though vital to the success of the earliest RDF equipment in England, would soon lead to problems when the JB radar went "up north" with the country's troops.

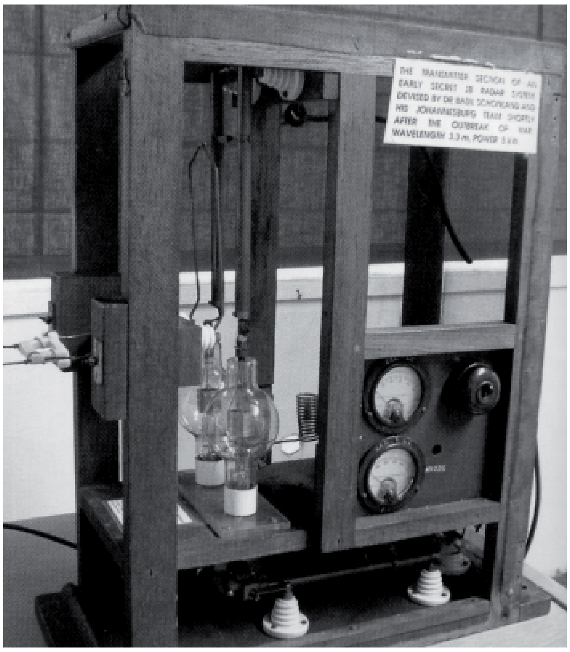


Figure 6. The JB1 radar transmitter in its wood-framed enclosure, showing the triode valves and the tuned lines.

Figure 7. The BPI building, with a radar antenna on the roof.

9. The First Radar Echo

December 16 was a public holiday in South Africa. The BPI was therefore closed. However, with the JB0 showing signs of functioning, Schonland and Bozzoli decided to go in to see if they could get the complete system to operate, and perhaps even detect a reflected signal from some object in the vicinity. Previous attempts to do this had been made, but none had been successful. The first test involved a mesh of copper wires, lifted to some appreciable altitude by hydrogen-filled balloons, which they hoped would act as a suitable radar reflector, but the JB0 registered nothing meaningful on its cathode-ray tube. The next test, arranged with the cooperation of the South African Air Force, involved a flight by a single-engine aircraft along a carefully planned route. The pilot was briefed, but no information was given to him as to the purpose of his strange mission. On the appointed day, with five pairs of eyes anxiously watching the radar screen at the BPI, no sign of the aircraft appeared. This was most disappointing, until it was discovered that the pilot had decided that the exercise seemed pointless, so he had detoured over his girlfriend's house instead!

The JB0's antennas, which were both dipole arrays backed by reflectors, were positioned on the roofs of two nearby university buildings. The transmitting antenna was situated on the roof of Central Block, the main university administrative building, while the receiving array was on the roof of the BPI (Figure 7). The equipment connected to each was housed in rooms immediately below the two antennas. The two radar "operators" – Bozzoli attended to the transmitter, while Schonland watched the cathode-ray tube of the receiver – were in direct communication with each other via the university's telephone exchange. This was reminiscent of JB and D again, between Johannesburg and Durban. They slowly steered their respective antennas from north to northwest, with Schonland keeping a close eye on the CRT screen. Then it happened: he shouted down the phone to Bozzoli that there was a reflection! Bozzoli dashed across from one building to the other, taking the stairs three at a time. Sure enough, there was a definite "blip" on the screen, so, together, he and Schonland moved the receiving antenna back towards north. The blip disappeared. Turning the antenna back to its previous heading restored the reflected signal to the center of the screen. The two men rushed up to the BPI roof, and looked northwest. There, some 10 km away, was a well-known Johannesburg landmark, the Northcliff water tower, atop a hill known as Aasvoelskop. One or the other was clearly the radar target, the first ever seen in South Africa that day in December, 1939 [2, p. 182].

10.The JB1: An Operational Radar

Schonland informed Col. Collins of their success, and also indicated that the ranks of the SSS were increasing by one. A very young Frank Hewitt, with a freshly minted master's degree in Physics under his belt, from Schonland's own university in Grahamstown, had recently joined the BPI. He had been offered a position there by Schonland some while before, with the intention that he would join the lightning research group. By the time he arrived, the face of the BPI and the work they were now involved with had significantly changed. Hewitt was not immediately admitted to the inner circle. As he mentioned in his correspondence with me many years later, he was given something to read about lightning, while his colleagues took time to get to know him. Once he had apparently passed whatever scrutiny was required – and had demonstrated that he was more than handy with a soldering iron, having been an enthusiastic designer and builder of radio receivers from his schooldays – he was put in the picture by Bozzoli, and immediately given the task of designing a monitor for Gane's transmitter.

Now that they had a target – and a fixed one, at that – that they could use to make measurements, Schonland's team set about peaking up their equipment. They soon were able to detect aircraft targets at a distance of 15 km and, within a month, they had increased the range to 80 km. Word then reached the BPI that the British equipment which they were expecting would be delayed indefinitely. This was a major blow, but Schonland, confident that the SSS now had the ability to do more than just learn the techniques of radar and could actually construct a setup themselves, proposed to Collins that they should go ahead and design a radar suitable for use in the field. Collins readily agreed, and the team switched all its efforts into producing their first operational radar, the JB1.

The design team was soon depleted, because Phillips and Roberts had to return to their universities, as the new academic year had begun and their services were required in their teaching roles. However, Hewitt was fast proving his worth. He was next given the task of designing an indicator using a so-called magic-eye tube, which would show when the spongy lock was actually locked. Bozzoli now assumed the mantle as chief radar design engineer. He immediately redesigned many aspects of the system, including Gane's

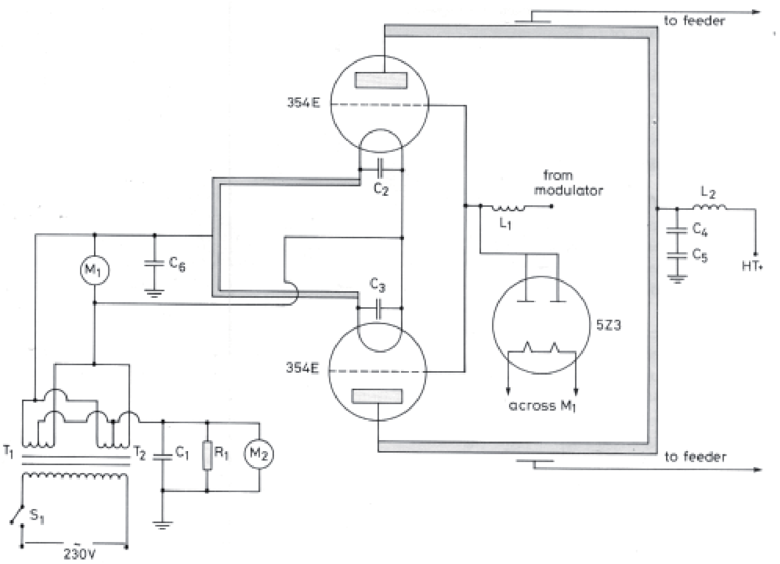


Figure 8. The JB1 transmitter schematic.

rather temperamental transmitter. It still used two triodes in a push-pull shock-excited oscillating amplifier (Figure 8) but now included a clamp circuit provided by the 5Z3 diodes on the two grids. Its purpose was to prevent the grids from going positive, and so causing the amplifier to break into uncontrolled oscillation, which it had been prone to do. Bozzoli also altered the IF amplifier of the receiver, considerably simplifying it while increasing both its gain and its bandwidth, making the latter more appropriate to the pulse width of the transmitter. However, for some inexplicable reason, he decided to leave the spongy lock in place, even though there was no apparent need for it. Hewitt soon mastered the theory underlying this strange circuit, and his lock indicator worked well. This was very fortuitous, for in the not too distant future, he would have to carry out a redesign of that circuit under far from ideal circumstances, when the JB1 was in service near Mombasa, in Kenya, performing its first operational role.

The JB0 had been a crude laboratory "lash-up." By comparison, the JB1 had the appearance of a solidly-constructed piece of broadcasting equipment, as might have been expected given Bozzoli's pedigree. Rack and panel construction was the order of the day. The receiver, the modulator and timing circuits, and their power supplies all occupied solid steel racks, about 1.5 m high and of the standard 19 in (48 cm) width (Figure 9). However, the transmitter remained very different. It was housed in a stout wooden cabinet, with all four sides being made of separated, fine metal gauze, such that the inner workings were all visible. This was done so as not to de-*Q* those two copper tuned lines that determined the operating frequency of the radar. However, the impression given to any uninformed observer was more akin to a birdcage than a rather special piece of electronic equipment!

A trial of the JB1 was immediately called for over the sea, because its first operational role was to be in providing cover against air attacks off the coast of Kenya. This was all driven by the fact that the Italian campaign in Abyssinia (the present-day Ethiopia) was showing signs of advancing further south. South Africa was about to send an infantry brigade to defend the British colony of Kenya from attack by Mussolini's army, and to then drive the Italians out of East Africa altogether.

The radar trial took place in June 1940, just north of Durban, at a place called Avoca. The SSS were now in uniform. Major Schonland was accompanied by Captain Gane and Lieutenant Hewitt, and a recently-recruited Post Office technician by the name of Anderson, rapidly promoted to Staff Sergeant. There were very few regular flights by aircraft on which to test the JB1. However, the roadstead off Durban was extremely busy with shipping, thereby

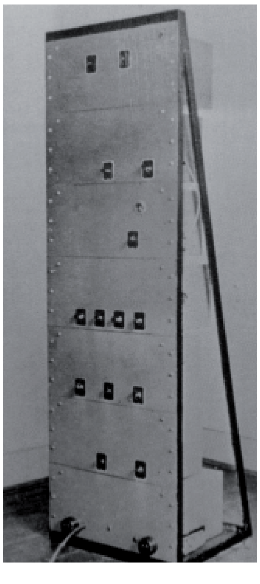


Figure 9. The JB1 receiver, showing the rack and panel construction.

providing excellent targets as well as a new role for the South African radar. It performed very well, and enabled the operators to gain considerable experience in using the equipment. A strange and rather surprising phenomenon was noticed, as well. Numerous target echoes appeared when no ships were visible at all. Hewitt and Gane believed they were ships beyond the horizon, but Schonland was skeptical. To settle this, he promised them all a meal at Durban's best hotel if the ships actually came into view. Eventually, they did. The explanation was anomalous propagation caused by atmospheric ducting. The experience turned out to be very useful, for it was to occur many times in the future. Schonland's men duly got their promised meal [2, p. 189].

11. The SSS at War

On June 16, 1940, a convoy of three ships left Durban, bound for Mombasa, in Kenya. Onboard were troops of the 1st South African Division, and with them was the JB1 radar with its SSS radar operators: the same three men who had tested the equipment in Durban just a couple of weeks before. Their commanding officer, Major Schonland, would be flying to Mombasa on an aircraft of the South African Air Force (SAAF) to meet them there in a week's time. The radar was to be set up near the village of Mambrui, just north of Mombasa, on a site selected for it by the gunners of the South African Anti-Aircraft Brigade, whose task was to defend the nearby airfield from air attack by the Italians. Expectations were high, and all eyes were on the SSS and its equipment.

They immediately ran into problems. Electrical power to operate the JB1 was provided by a diesel generator purchased in Mombasa. Unfortunately, when under load, both the voltage and the frequency were most unstable, and they exceeded the range of the JB1's spongy lock. The result was that the various timing pulses of the radar were all awry. The spongy lock, despite its intended purpose, was unable to stabilize the system. It was at this point that the young Frank Hewitt really showed his mettle, by effectively redesigning that part of the timing system, and making the necessary circuit alterations under anything but ideal laboratory conditions. The fact that Schonland had drummed into the SSS the need for absolute secrecy, so that they could never be accused of betraying the secrets of British radar to a living soul, meant that they had taken no circuit information with them. However, Hewitt's construction efforts in Johannesburg now bore multiple fruit. He had committed the spongy-lock circuit to memory, and he also knew the placement of all its components on the chassis. While Schonland anxiously watched, his young colleague produced a solution that stabilized the JB1's display on the screen, and the radar was in operation.

The JB1 was calibrated by tracking the daily flight of an aged Junkers J 86 aircraft of the SAAF that had been pressed into military service from its usual role as a transporter of civilian passengers around South Africa. Back at the BPI in Johannesburg, Bozzoli, who was in charge of the production of a series of JB1s while also beginning to work on new developments, was anxiously awaiting news of the radar's performance in Kenya. This soon arrived by way of a suitably enciphered telegram from Schonland. In order to deceive the enemy should the missive be intercepted, Schonland had devised a code whereby the maximum range achieved by the JB1 – a figure of much interest to all at the BPI – was added to Schonland's age. It was received, decoded, and then read with considerable satisfaction.

In the six months that the JB1 was in service in Kenya, it tracked enemy targets just once, for enemy aircraft appeared just once! The Italians had been expected to mount their attack on Mombasa's airfield by approaching from over the sea, and that was where the radar was watching. However, on the only occasion when they came, two aircraft approached from exactly the opposite direction. They flew in from behind the JB1's antenna, dropped their two bombs, and then continued on out to sea. It was then that the radar tracked them for about 55 km before the two blips on the screen eventually disappeared into the noise. The fact that the open-wire feed lines to the antenna wound themselves around the mast if 360° rotation was tried posed an operational problem. This encounter with the enemy coming from behind led to a special request being made to the BPI for a solution.

12. An Encounter with the RAF

The SSS had been sent to Mombasa to provide radar cover because there was none at all in Kenya. Quite unbeknown to the South Africans, the Royal Air Force was concerned about this, and had dispatched an officer to assess the situation, and report back to his headquarters in Cairo. He was Flt. Lt. J. F. Atherton who, in civilian life, had been a member of Watson-Watt's radar entourage in England. On his arrival in Mombasa, Atherton was surprised to discover that the South Africans had already set up a radar station in the country, with more to follow. However, his report was rather condescending about what he had seen. He said the South Africans were already operating their "elementary homemade RD/F [sic] in the area." He said the sets were of little practical value in view of their limited performance [2, p. 192-193]. Worse was to follow.

In his discussions with Schonland, Atherton had learnt of the political divisions between government and opposition in South Africa, and the presence of some in the country who had decidedly anti-British views. Schonland had emphasized to him that the SSS therefore treated the existence of radar as a matter of great secrecy, even to the extent of not divulging its existence to anyone beyond the very privileged few. Certainly excluded were many within Defense Headquarters in Pretoria, who would not accept that South Africans should be expected to fight beyond the borders of their country, while some even believed they should not be fighting for the Allied cause, at all.

However, Atherton completely misconstrued this. He reported to the RAF HQ in Cairo that Schonland's own headquarters – in other words, the SSS at the BPI – could not be trusted with the secret of British radar! The SSS had thus suffered ignominy on two fronts: their equipment was considered inadequate, and their trustworthiness was doubtful. The complexities of South Africa's politics looked like it was scuppering the country's involvement with one of Britain's most important wartime developments. Thankfully, better-informed minds in London soon prevailed. A cipher telegram was sent from the Air Ministry to Cairo. This informed those concerned that Britain had made a full and frank disclosure on RDF to all its Dominions, and as a result, there would be no possibility of discouraging any of them from conducting research or operating RDF systems.

13. The Suez Canal

By the end of 1940, the war in the Middle East was at a critical point. The British army, with some of its Dominion allies alongside, was now fighting in the Western Desert against the German Afrika Korps, soon to be under the command of Gen. Erwin Rommel. The Suez Canal was a prime target for attack from the air, with both German and Italian bombers seeking to close it. Radar cover was therefore urgently needed, especially as the British radars in the vicinity were required elsewhere as matters came to a head in the eastern Mediterranean, and especially in Greece. Schonland, now a Lieutenant Colonel, was asked to fly to Cairo for discussions with the RAF. The outcome was a request that the SSS and their radars should move from East Africa to the Sinai without delay, and take over the protective duties previously performed there by the radars of the RAF. Given recent events, this was a remarkable about-face by the British, and a particular boost for the South Africans.

Production of further JB1s was immediately stepped up at the BPI. There had also been a flurry of military promotions in the SSS. The four original members of the radar design team were all promoted to the rank of Major. In addition, Bozzoli was also designated Chief Technical Officer, and as such, was in effective command at the BPI, even though David Hodges from Durban, who had also joined the SSS, was appointed as Schonland's second-in-command. Recruiting of other technically qualified personnel was now in full swing, with special radar training courses having been set up at the three participating universities.

On January 8, 1941, a complete JB1 left Durban bound for Cairo, where it and its accompanying operators were met by Phillip Gane, who had flown there directly from Mombasa. The radar was immediately demonstrated to officers of the RAF, who were impressed. It was considerably smaller and hence more mobile than any British radar. Given its performance, which was keenly observed, it was deemed to be well-suited to its new role in providing radar cover of the Suez Canal zone. By mid-July, three JB1s were in operation along the Sinai coast at El Arish, Rafa, and El Ma'Aden. They initially had been used in parallel with a British radar, no doubt to compare their performance, and the outcome caused many a wry smile amongst the SSS. The JB1, appropriately sited with the sea ahead of it, outperformed the longer-wavelength (40 MHz) British MRU radar, operating right alongside it. The JB1s regularly tracked aircraft at distances of 120 km. They even had the occasional sighting of the island of Cyprus, some 400 km to the north: yet another example of the anomalous propagation first noted near Durban more than a year before. The South African radars were soon accorded official designations as SSS1, SSS2, and SSS3 in the RAF's list of radars operating in the Middle East [1, p. 564].

14. Coastal Radars Around South Africa

It had always been the intention that the radars designed in South Africa, as well as any of the British equipment that Schonland was able to muster, would be employed in the defense of South Africa's 2000 km coastline, and especially its major seaports of Cape Town, Durban, Port Elizabeth, and East London. It was feared that German armed raiders, posing as merchant ships, as well as the German U-boats, would be a significant threat to shipping around both the Atlantic and Indian Ocean seaboards. Later, after Japan had come into the war, both Japanese submarines and ship-borne aircraft were considered to be likely threats, as well.

The first JB1 radar to go into service in South Africa was at Signal Hill in Cape Town on May 22, 1941. However, it was not the first radar to be operationally used in the country. That honor belonged to the British ASV (Air-to-Surface-Vessel) radar, operating at 200 MHz. That was installed not in an aircraft, but on the Bluff in Durban, two months before. The much-promised British radars had thus finally begun to arrive in South Africa, but in very small numbers, and they were frequently incomplete. In June, an order was given for the BPI to construct 25 JB1s for use both in the Middle East and in South Africa. This was a task that Bozzoli efficiently organized, while also being personally involved in establishing the first coastal installations (Figure 10). This task was not without its problems. The insistence on complete secrecy about anything to do with radar (and, as a result, the SSS) introduced no end of administrative problems, which required careful handling. Bozzoli became very adept at this [5, pp. 42-44].

Schonland left Cape Town for England in March 1941. The purpose of his visit was to speed up the supply of radars, as there was clearly an urgent need for the more-sophisticated British equipment, which, by that stage of the war, already included the microwave radars using the cavity magnetron. Equipment began to arrive. These included the CHL (and its tropicalized version, the COL), both of

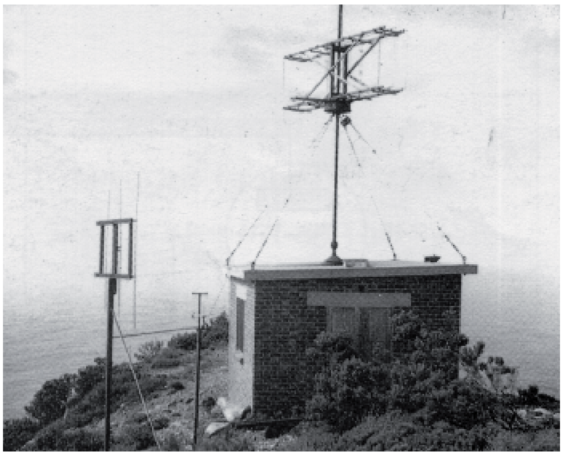


Figure 10. The JB1 radar situated at Cape Point.

which operated at 200 MHz; and the TRU, a scaled-down version of the CH radar, which worked at about 40 MHz. In addition, there were a few ASV and SLC radars, also 200 MHz equipment. The former was intended for use in aircraft, but was actually used on the ground in South Africa (as mentioned above). The SLC (known as Elsie) used five Yagi antennas mounted on a searchlight for accurate target acquisition and tracking.

The SSS had actually embarked on designing their own version of Elsie, when Major Noel Roberts was asked to provide such a radar for use by the South African artillery guarding the port of Mombasa, in Kenya. Roberts produced a complicated system, using a spiral time-base for the display, as well as air-blast cooling of the VT 58 pulsed triodes in the transmitter. It was called the JB2. However, its development was too rushed. On delivery to Mombasa, it proved unreliable, as well as being too complicated to set up in the field. It was thus abandoned [5, p. 27].

Virtually all the South-African-designed radars deployed around the coast were of the type soon to be designated the JB3. This was essentially a mobile radar (Figure 11), with the transmitter and its rotatable antenna in one vehicle, and the receiver plus its antenna in another. However, most JB3s were operated as fixed installations, once they had been driven to their sites. The first such unit was completed in April 1941. The antennas used are of some interest. The earlier dipole arrays had been superseded by a fully rotatable Sterba array backed by a similar group of reflectors, all mounted on a sturdy wooden frame. The problem referred to earlier of the feeders being wound around the supporting pole when the antenna rotated was solved at the BPI by using a magnetic coupler that allowed 360° rotation. Just a single such Sterba antenna was subsequently used for both transmitting and receiving. This was made possible by the inclusion of a transmit-receive (T-R) switch, consisting of two spark gaps at the appropriate points on a transmission-line stub that fired when the transmitter pulsed, thereby effectively isolating the receiver from its companion transmitter. This new radar was named the JB4. When in its mobile configuration, it became the JB5 [5, p. 34].

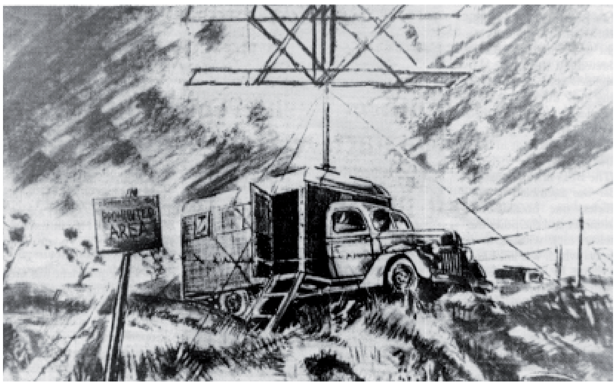


Figure 11. The JB3 mobile radar, from a charcoal drawing by the war artist, Geoffrey Long.

In all, by the end of the war in 1945, more than 30 radar stations of various types were operating around South Africa's very long coastline (Figure 12). Remarkably, given its inauspicious beginnings, the SSS had designed and built 31 JB radars in all, beginning with the JB0 prototype, which started it all in late 1939, to the JB5 of 1944. These would then be augmented by a variety of British radars, with the microwave equipment in the form of the British types NT 271, 273, and 277 – which began arriving in South Africa in 1942 for use by the coastal artillery – representing the pinnacle of technical development. The step change in electronic sophistication, from that earliest JB "lash-up" to those British-designed 10 cm (and, ultimately, the 3 cm) radars, clearly showed how the pressures of war undoubtedly determined the exceptional rate of progress that had been made.

15. Radar Training at the BPI

It soon became apparent that the need for competent and well-motivated radar operators would place severe strains on the available skilled manpower in South Africa. Just as had occurred in Britain, the decision was taken to use women, most of whom had a variety of university degrees. All underwent a course of military training, as well as dedicated instruction in the art of operating the radars, and in communicating the information to the filter rooms situated in the four major port cities. Their training took place mainly at the BPI. These women became members of the Women's Auxiliary Army Service (WAAS). They were then posted to radar stations around the country, where they were under the command of an SSS technical officer, whose function was to run the station while keeping the radar equipment "on the air" (Figure 13). By 1945, more than 500 female radar operators had been trained. They carried out by far the bulk of the operating and monitoring of those radars around the country. In addition, around 300 male technicians were trained at the three participating

Figure 12. A map showing the position and the predicted coverage from the radar stations around the South African coast.

universities around the country to be able to service and maintain all the various radar types [6].

The strength of the SSS when the war ended in Europe in May 1945 had doubled in size from the numbers serving at the end of December 1941. There were then 145 officers, of whom 28 were women, and 1407 other ranks (507 women). As well as those serving throughout South Africa, two SSS contingents were posted to Italy as part of the Allied invasion, the purpose of which was to drive out the Germans following the Italian surrender in September 1943. The SSS set up two Field Radar Stations (Nos. 70 and 71 FRS) near Naples and Milan, respectively. There, they operated a variety of British and American equipment, including the radio navigation systems Gee and SHORAN. In addition, the SSS provided a contingent to the South African Force squadron that was based at Takoradi on the Gold Coast (now Ghana) in West Africa, from where it carried out anti-submarine patrols. The Wellington aircraft involved were fitted with the British ASV MkII radar, as well as IFF which, by then, was a standard feature on most Allied aircraft. It was the responsibility of the SSS to install and maintain it all, a task made even more challenging by the intense humidity of the tropical environment. In addition, they provided blind-landing aids, known as Babs (Blind Approach Beacon System), on the aerodrome.

16. The Personalities

In concluding this account of the little-known South African involvement in the wartime radar story, it is perhaps worth just mentioning the subsequent careers of some of the major players.

Basil Schonland never returned to South Africa after going to England in 1941, because his services were immediately required there. Initially, he became the deputy to Prof. John Cockcroft at the Air Defense Research and Development Establishment (ADRDE). He soon succeeded Cockcroft when the organization expanded, and was renamed the Army Operational Research Group (AORG). Schonland became its first Superintendent. The AORG was responsible for the radar activities of the British Army, as well as myriad other issues related to the interplay between science and soldiering. Along with the operational research section established by the RAF, Schonland's AORG was the pioneer in the field of scientific soldiering. One of its most important contributions to Britain's war effort was the marked improvement in radar-controlled anti-aircraft gunnery brought about by operational research [2, p. 231]. Just prior to the invasion of northwest Europe by the massed US, British, and Canadian armies in June 1944, Schonland was appointed scientific advisor to General (later Field Marshal) Bernard Montgomery's 21 Army Group. By now a Brigadier, Schonland served throughout that campaign until December 1944. At that point, when it appeared to many that the war would soon be over, he was recalled to South Africa by his Prime Minister, Field Marshal Smuts, for the specific purpose of drawing up plans for the establishment of the Council for Scientific and Industrial Research (CSIR). Schonland served as the CSIR's first President for five years, before returning briefly

Figure 13. Women operators using the COL radar in South Africa.

to the BPI and lightning research. However, his presence was soon required in England (and elsewhere too, judging by the many offers he received). In 1954, he again joined his old Cambridge colleague, John Cockcroft, this time at Harwell, the home of Britain's Atomic Energy Research Establishment. Schonland served as Cockcroft's deputy for four years, before taking over from him as Director in 1958. He retired in 1960, and was knighted by the Queen for his services to British and Commonwealth science. In 2000, some thirty years after his death, Schonland was elected as South Africa's scientist of the 20th century [2, p. 579].

"Boz" Bozzoli became Head of the Department of Electrical Engineering at Wits, Dean of the Faculty of Engineering, and, in 1969, Vice-Chancellor, the senior academic and administrative position at the university.

Frank Hewitt established the Telecommunications Research Laboratory (TRL) at the CSIR. Amongst his senior staff were six other members of the wartime SSS. He then became Deputy President of the CSIR. Two of those TRL personalities – whose names haven't appeared in this account, although their technical expertise was highly valued – were T. L. Wadley and J. A. Fejer. Both made major contributions to post-war radio science. In 1957, Wadley invented the Tellurometer, a microwave distance-measuring instrument that revolutionized land surveying. Before that, in 1954, he designed the HF radio receiver that set new standards in the performance of such equipment. It soon became the mainstay of the Royal Navy's HF communications when Wadley's technique was adopted by the Racal, a UK electronics company, who turned it into their famous RA17 continuously-tunable receiver. Jules Fejer was a brilliant theoretician who provided the mathematical back-up at the TRL when Wadley was developing the Tellurometer. He then moved to Canada and from there to the USA, where he made very significant contributions at the University of California to the science of ionospheric backscatter.

17. References

1. Anonymous, "Disclosure of R.D.F. Information to the Dominions," *Signals, Volume 4, Radar in Raid Reporting*, UK, The National Archives, AIR 41/12, 1950.

2. B. A. Austin, "*Schonland: Scientist and Soldier*," Bristol, UK, Institute of Physics Publishing (Taylor & Francis), 2001.

3. R. Hanbury Brown, "*Boffin: A Personal Story of the Early Days of Radar, Radio Astronomy and Quantum Optics*," Bristol, Adam Hilger, 1991, p. 13.

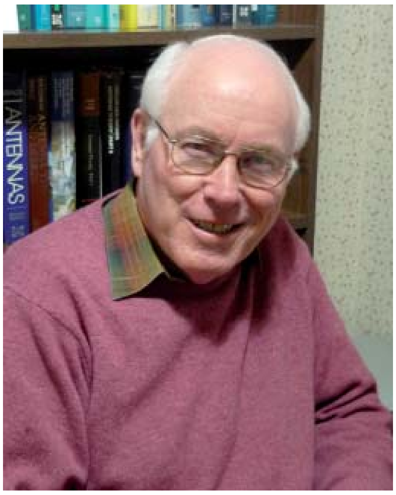
4. L. Brown, "*A Radar History of World War II*," Bristol, UK, Institute of Physics Publishing (Taylor & Francis), 1999.

5. P. Brain, "*South African Radar in World War II*," published privately by the SSS Book Group, 1993.

6. B. F. J Schonland, "The Work of the Bernard Price Institute of Geophysical Research, 1938-1951," *Transactions of the SAIEE*, **42**, August 1951, pp. 241-254.

Introducing the Author

Brian Austin was born in Johannesburg, South Africa. He completed his electrical engineering degree at the University of the Witwatersrand in 1969, and subsequently obtained his MSc (Eng) and PhD from the same university. He spent a decade in industry, working for the Chamber of Mines Research Laboratory. There, he led the team that developed a hand-held medium-frequency SSB transceiver for direct-through-rock communications in deep-level gold mines. He then became an academic, first at his alma mater, and then at the University of Liverpool in the UK. His research interests covered the fields of antennas and radio propagation, mainly at HF, as well as the history of radio and radar technology. He published widely in all those areas. He is a Fellow of the IEE (now the IET), a Senior Member of the IEEE, and was also the UK representative to URSI in the area of Fields and Waves. He has been retired



Surprising Findings from the Hungarian Radar Developments in the Era of the Second World War

István Balajti[1] and Ferenc Hajdú[2]

[1]Military Science Faculty
National University of Public Services
Budapest, Hungary
E-mail: Balajti.Istvan@uni-nke.hu

[2]Editor-in-Chief of *Haditechnika*
H-1135, Budapest, Hungary
E-mail: Hajdu.Ferenc@hm.gov.hu

Abstract

New scientific findings always have historical roots that are important for researchers to know, of course including radar researchers. Different ideas and viewpoints from the early development of radar help us to get the full picture of our research subjects when we try to develop new radar systems based on modern technology. Until now, it was thought that Hungary had had a relatively small impact on radar technology compared to other countries, but it is clear today that this was not true. Hungarian experts and scientists achieved significant results. About one-third of Hungarian radar experts died during the Second World War, and another one-third immigrated to western countries and got a job in companies there. At the end of the Second World War, the former Soviet Union took all Standard Co. radio and radar manufacturing equipment, including the Tungsram Co. laboratories with the operational radars. Today, it is time to draw attention to the achievements reached by the Hungarian radar community. This paper is a brief summary of the facts that became public late after WW II. The authors hope that this article helps to open the archives of the successors of Tungsram Co., Standard Co., and Philips Co. to further investigate the remaining uncertainties of Hungarian radar developments, as well as the details of the first moon-detection trials of Dr. Bay's team.

1. Introduction

The invited paper on "Radar Developments in Hungary During World War II (WWII)," and its presentation during Microwave and Radar Week 2016, held in Krakow, May 2016, drew considerable attention [1]. The feedback received from the audience showed interest in a more detailed and comprehensive review of Hungarian microwave investigations, radar research, and development-related topics of that time. It inspired the authors to further investigate the subject. The number of publications that introduced the work of Hungarian scientists and engineers – or radar researchers with Hungarian roots – contributing to world radar technology was very limited. This article aims at reducing this gap by drawing attention to the Hungarian "hot spots" of radar historical roots, while enlightening Hungarian radar research, development, and manufacturing successes in the world's related global picture. Today, while the methodology of radar project management is at the focal point of customers' interests, details on Hungarian project-management standards in these times aim to give ideas for current top-level radar manufacturing management, i.e., how to increase the efficiency of modern radar projects. Limited information on the civilian aspect of Hungarian radar engineering was introduced in [2], while its list of references contains the names of today's civil-aviation contributions. Further information can be read in [3], which gave a short introduction to the Hungarian radar and air-defense system structure, but some technical information was obsolete. Very important books giving additional information on the matter were [4, 5].

2. Dr. Jáky and the Royal Hungarian Honvéd Institute of Military Technology

The Trianon treaty (paragraph 115) [6] deprived Hungary of the opportunity to create an army corresponding to the standard of that time. Military technological research

Figure 1. Dr. József Jáky, Hungarian radar developer, superior manager [7].

and development activities were also prohibited. Between the two world wars, the military leadership used every trick to circumvent the clauses of the treaty. To avoid the science of military technology being swept away by the army, dozens of well-educated officers who had gained experience in the battlefields of WW I were enrolled at the Royal Joseph Technical University in an organized manner [7].

At the focus of these military technical, scientific, and industrial achievements there was a Hungarian military engineer (Figure 1). He was a man whose course of life was almost unknown, not only to foreign specialists, but to the Hungarian scientific public life, as well.

József Janicsek was born on March 26, 1897, in Eperjes. His father, Dr. József Janicsek, was a high school teacher. The son changed his own name into the more-Hungarian Jáky. He passed high school in Eperjes with excellent grades, and he then registered with the Faculty of Natural History and Mathematics of the Pázmány Péter University. He gained admission to the Eötvös College. In 1915, he voluntarily joined up with the imperial and royal 34th infantry regiment, in which he passed six months at the Russian front line. After WW I, he was commanded to the Technical University, to be trained at the Faculty of Mechanical Engineering as a second-year student. In addition to this, he had to teach at the Ludovica Academy. Preparatory training was going on in all fields of military technical sciences (Figure 2).

In 1920, at a barracks besides the Technical University, the Institute of Military Technology (TEKI was the abbreviation of its Hungarian name at that time) was established. This was where considerable development activities were carried out for all fields of military science. In 1928, the of staff of TEKI numbered 47, comprising engineers and technicians. They worked on more than 100 development topics. This was only possible with the cooperation of professionals of science, industry, and the reorganization of the Royal Hungarian Army. Everything was secretly done, in spite of the controllers of the Entente Powers.

The Royal Hungarian Honvéd Institute of Military Technology (hereafter, IMT) was officially established. Its electronics laboratory began to work with the aim of establishing communications between troops, harmonizing theoretical problems and practical opportunities, designing components of wired and wireless communication, and bringing them into production. The IMT did experiments on Hungarian military radio equipment, e.g., the R7-type

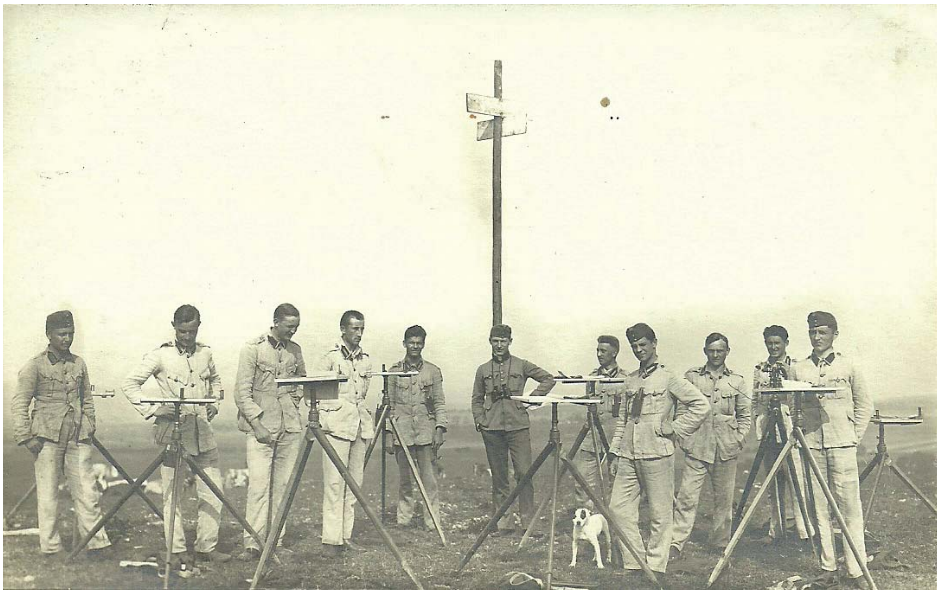


Figure 2. Capt. Jáky among future military signal engineers.

Figure 3. Maj. Jáky to the right, with the R7 type of Hungarian military radio.

radio (Figure 3), together with Edvin Istvánffy (Rainer), from the end of the 1920s, with whom this cooperation continued, as described later.

The young communications engineers worked together with János Csonka (1852-1939), also known from the Technical University. He manufactured a dynamo driven by an engine for charging the batteries of military radios. Experiments were also carried out on quartz-controlled military radios, but they were considered too expensive.

From October 1, 1938, Jáky was the appointed head of Department 4 of the IMT. He was promoted to Lieutenant Colonel in 1940, and then Staff Engineer Colonel in 1942. Having defended his thesis on electrical methods of measuring bullet/muzzle velocity, he obtained his Doctorate in Technical Sciences in 1941 [7]. Figures 4 and 5 show the antenna and the analog computer with the weather station on top of the bullet/muzzle-velocity-measurement equipment.

3. The Impact of World Historical Circumstances on the Initialization of Hungarian Radar Development

In September 1939, Germany requested Hungarian territory against the invasion of Poland. The request was rejected, and the border opened for 180000 Polish refugees. Hungarian-German relations cooled down in all fields of cooperation.

In August 1940, the relations between Hungary and Romania were close to local conflict, which could have cut Germany from access to the Romanian oil fields [8]. The German government exerted political and economic pressure on Hungary to avoid a conflict. The Wehrmacht even got the task to develop a plan for the occupation of Hungary. The plan was shown to the Hungarian government.

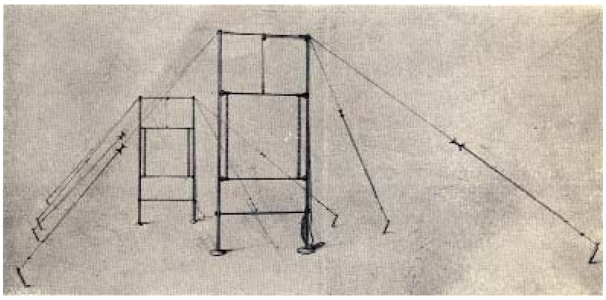


Figure 4. The antenna system of the bullet/muzzle-velocity measurement equipment.

On November 20, 1940, Hungary was forced by Germany to join the Allies of the Axis, but developed alternate plans to safeguard the independence of the country. One of the plans was the establishment of the Hungarian Emigrant Government in the USA, while an amount of 5 million USD (77 million to 80 million USD today) was transferred to the USA [8].

In March 1941, Germany requested Hungarian territory against Yugoslavia. This request was also rejected, and the Hungarian army partially mobilized to defend Hungarian territory.

On April 3, 1941, the questionable suicide of the Hungarian Prime Minister, Pál Teleki (1879-1941), resulted in Hungary joining the German attack against Yugoslavia.

On June 22, 1941, Germany attacked the Soviet Union, but Hungary remained neutral.

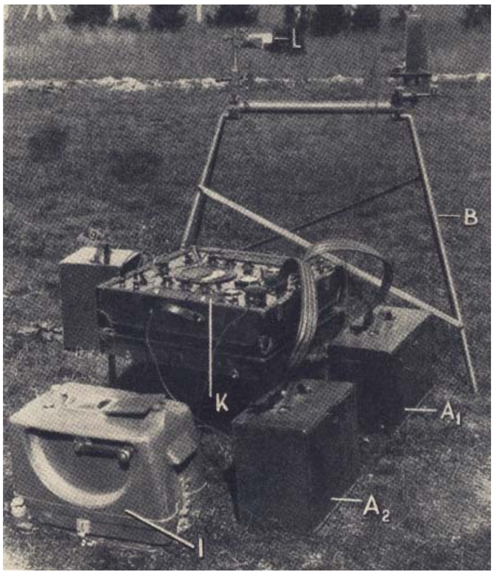


Figure 5. The bullet/muzzle-velocity measurement equipment with a weather station.

On June 26, 1941, bombers manufactured in the former Soviet Union bombed the Hungarian town of Kassa.

Hungary contacted its German ally in order to size up the opportunity to cooperate and share military technology.

During the Battle of Britain, the German and British adversaries got to know each other's radars to some extent: raids (e.g., Bruneval) and crashed aircraft (e.g., Rotterdam) also revealed technical details. Jamming only revealed that the opponent was aware of carrier frequencies and the mere fact that radar(s) were operating, without technical details. The only exception was that when the Hungarian radar developers got information on chaff dropped against the Würzburg radar, they acquired knowledge about the radar's operational carrier frequency [23]. Certainly, Hungarian analysts evaluated the collected information resulting from the Battle of Britain, and they came to the conclusion that air raids against Hungary were unavoidable. The application of radar could be the only opportunity for Hungary to effectively defend itself. Studies prepared by German, Italian, and Hungarian military experts showed that the air-defense environment needed radar. The question was, how to obtain it?

In December 1941, a Hungarian delegation, led by Major General Hellebronth, visited Germany. The members of the delegation were Staff Engineer Colonel Dr. József Jáky, head of the Electronics Department, and Staff Engineer Major Imre Balassa. During the presentation, they got to know the German Freya air-surveillance radar, the small "Würzburg" fire-control radar, the giant "Würzburg Riese" fighter-control radar, and the Lichtenstein airborne radar. Knowing the specifications of these radars, the leadership of the IMT made a plan for two variants for the air defense of Budapest and the whole country. They calculated the required quantity of radars for both cases. IMT experts considered that four air-surveillance radars, 30 fire-control radars, 10 fighter-control radars, and four airborne radars were necessary for the air defense of Budapest. As far as the air defense of the whole country was concerned, they requested 100 air-surveillance radars, 60 fire-control radars,

Table 1. A count of the number of staff of the IMT at the end of 1944.

Sections	**Subsections**	**Officer**	**Civil**	**Enlisted Men**
Staff	Staff of military senior engineer	2		5
	Command	7	3	46
	Finance office	2		11
I. Section	Ballistics	10		1
	Ammunition	14		
	Aim and sight	9		
II. Section	Military bridges and transport	8		1
	Military engineering	5		
	Prime mover	4		
	Camouflage	2		1
III. Section	Hand weapon	7		3
	Artillery and mortar	14		
	Aircraft weapon	6		
	Coaching of armaments industry	26		2
	Mobile repair team	5		2
	Archives and reproduction		4	8
IV. Section	Line signal devices	6		1
	Radio and microwave	5	1	2
	Aggregates	4		
V. Section	Armored vehicles	7		1
	Off-road vehicles	4		
	Engine	6		3
	Truck and superstructure	3		
VI. Section	Chemical	16		2
	Explosive	8		1
	Material	6		1
	Fuel and slush	7		1
VII. Section	Editing of technical specification	10		4
Test fields	Hand weapon (Örkény)	1		32
	Artillery (Hajmáskér)	2		90
	Engineer (Hárossziget)	3	1	33
	Aircraft weapon (Ferihegy)			8
	Armored vehicle (Hárossziget)	2		10
	Signal (Vác)			7
Total		**211**	**9**	**276**

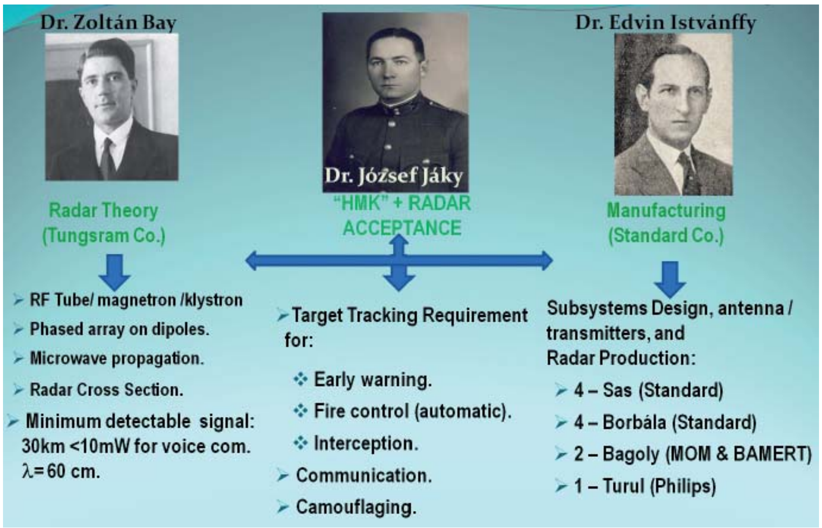


Figure 6. The organizational structure of the Hungarian radar production.

100 fighter-control radars, and 100 airborne radars. On the other hand, the German ally offered one Freya, three small "Würzburg," and two giant "Würzburg Riese" radars, for sale. As regards the Lichtenstein radar, Germany gave a cold shoulder to the request for the purchase of this type of radar, or for the purchase of licenses or technical cooperation.

This unfavorable result was far from the expectations of Hungary, since several modern Hungarian technical devices were supplied to German military industry. For example, there was an order placed from Telefunken to upgrade the mean time between failures of the LD-150 triode, which was less than 50 hours. Andor Budincsevics (1905-1995), an employee of the research laboratory of the Tungsram, got the task. Basic research was performed, and the new triode became so successful that since 1943, all Würzburg radars used these new tubes. Industrial opportunities launched other programs to construct an electron tube with special parameters "sensitive to blue light," and to enter it into production. This tube became the heart of the navigation system of the German V-2 ballistic missiles, and became known even to a Soviet military advisor in the middle of the 1950s [9].

Our allies this did not give, but took away. Although Dr. Jáky twice participated in a study tour in Germany, the Germans did not provide him with any technical information.

It may be assumed that the leadership of the IMT was ready for this eventuality, since the preparation of radar development lead by Dr. Bay and by Dr. Jáky was already underway in October of 1941, in spite of the leadership looking for opportunities to arrange German imports and cooperation. Knowing how the IMT functioned, we can safely say that Staff Engineer Colonel Dr. József Jáky was the father of the idea that home-developed radar could be (and should be) manufactured. He knew the domestic military demands and the domestic technical elite, and personally and together with colleagues of the Fourth Department of the IMT, he had a good scientific knowledge that enabled him to organize the work of scientists, engineers, technicians, and manufacturers, and to draw up military requirements [10]. The staff count of various sections of IMT by the end of 1944 is listed in Table 1 [11].

Dr. Jáky was appointed Ministerial Commissioner responsible for radar matters. Together with Prof. Dr. Zoltán Bay, Dr. Edvin Istvánffy, and his colleagues, he was charged with the task of launching the development and manufacturing of Hungarian radar. In this position, he was the military commander of Bay and Istvánffy. In 1943, when as members of a delegation they together visited Germany, the Freya and Würzburg radar were demonstrated to them from a distance. This made it quite clear that Germany would not furnish Hungary with radar, nor with technical assistance.

4. Organizational Structure of the Hungarian Radar R&D and Manufacturing

In order to achieve this goal, three teams were set up on Jáky's initiation, as Figure 6 shows. The team under Dr. Jáky's direction elaborated the military operational and technical requirements for the military radars to be developed. All military and technical requirements of the radars were combined in the statement of work (SOW), the so-called "HMK" (Common Military and Technical Requirements). The peculiarity of the "HMK" was the brief and compact nature of the structure, commonly written in 15-20 pages, with a focus on the benefit of the new equipment. It was compulsory to apply existing standards that were relevant to the subject matter. Using standards had the advantage that all contracted firms with IMT precisely knew not only the requirements, but also the required test procedures to be fulfilled. A further advantage of this type of SOW was that very complex and classified subjects, such as radar developments, could be subcontracted without giving details on the whole project.

Figure 7. The advanced Hungarian radio production company, Standard Co. (courtesy of Nándor Wlassits) [4]

The "HMK" prepared by IMT members was accepted, authorized by a committee with representatives of military users, main contractors, subject professional scientists, and IMT. The "HMK" became a partner of the contract after authorization. Dr. József Jáky's leadership developed the "HMK," resulting in the construction of the following four types of radars in Hungary: the Sas (Eagle) air-surveillance radar; the Borbála (Barbara) fire-control radar; the Bagoly (Owl) fighter-control radar; and the Turul (Hungarian mythological bird) airborne radar. Precise requirements for the airborne radar were taken over by Philips Hungary Co. Military requirements were formulated for target detection and tracking for early warning, fire control, and fighter control. Required communications among radars, fighters, and the air-defense command center located in Budapest for wired and wireless communications were constructed. Special attention was given to the camouflaging requirement. This team was responsible for project management, military acceptance tests, and handover of the radars to the military user, with all related training, documentation, and follow-on support.

The team of scientists was hallmarked with the name of Prof. Dr. Zoltán Bay, and located in the Tungsram Co. Without attempting to be comprehensive, we mention some names: Viktor Babics (1900-1982), Andor Budincsevics (1905-1995), György Dallos (1910-1945), Antal Horváth, György Papp (1912-1964), Ferenc Preisach, Károly Simonyi (1916-2001), Antal Sólyi (1913-1946), Zoltán Szepesi, Jenő Pócza (1915-1975) Ernő Winter (1897-1971), and István Barta (1910-1978). Their initial technical task was to clarify uncertainties required to detect targets located at a 100 km distance. They had to solve the problem of generating and receiving microwaves, find solutions for a powerful and reliable transmitter, an antenna system, the required receiver amplification at minimum noise level and optimal bandwidth, measure the peculiarities of RF signal propagation, determine the radar cross section of different target types, and measure the minimum detectable signal level required to detect targets at a 100 km range from the radar. The members of the team knew the limits of triode excitation of oscillations and the theoretical potentials of the magnetron and klystron. However, because of wartime and scarce resources, they decided to choose a triode solution. In the laboratory of the Tungsram Co., Winter, Dr. Szepesi, and Budincsevics developed the EC 102 electron tube, capable of delivering 2 W power at an anode voltage of 250 V and at a wavelength of 50 cm to 60 cm.

Dr. Zoltán Bay was born on July 24, 1900, in Gyulavári, Hungary. He graduated in Debrecen, at the Reformed College. He studied as physicist at the Budapest Scientific University. He then got the position of Director and Professor in the Theoretical Physics Department of Szeged Scientific University. Dr. Zoltán Bay became the Director of the Research Institute of the Tungsram Co. in 1936, and the head of the Nuclear/Atomic Physics Department of Budapest Scientific University in 1938. Between 1938 and 1944, he was a member of the Secret Scientific Committee of the Hungarian Institute of Military Technology. After the war, he left Hungary with his family for the United States. He was a professor at George Washington University until 1955. In 1955, Zoltán Bay became head of the Department of Nuclear Physics at the National Bureau of Standards (NBS, today called NIST), where he measured the velocity and frequency of light using a previously unknown measurement method. Because of Bay's research, the 1983 conference of the International Weights and Measures Bureau accepted the definition of a meter (metre) as recommended by Zoltán Bay as a standard. Dr. Bay died at the age of 92, on October 4, 1992 in Washington DC.

The industrial team was headed by Dr. Edvin Istvánffy, who was the technical director of the Standard factory. Lipót Aschner (1872-1952), the general director of the Tungsram company, was responsible for general

Figure 8. The advanced Hungarian radio production company: Tungsram Co. (courtesy of Nándor Wlassits) [4].

management of radar manufacturing, subcontractors, etc. Starting radar manufacturing proved to be a particularly complex task. Several small firms were contracted to produce various subassemblies and main components, while the assembly itself was carried out at the premises of the companies Bamert, Standard, and Philips. Lipót Aschner mentioned that he could never have thought he would finance a project of which he was not allowed to know the content. At many places, the work was done without knowing the final goal. This team, with Géza Sárközi (1903-1985) as a member, developed the planar phased array of the "Sas" air-surveillance radar. The Philips TB2/500 high-power tube was selected for its transmitter, because this powerful electron tube, used for broadcasting, needed a small modification to be implemented for "m" band (called the "VHF" band today) radar usage. This team carried out final assembling, installation, testing, and maintenance of different radar types, with the cooperation of team members of Dr. Bay.

Dr. Edvin Istvánffy was born on January 4, 1895, in Párkány, Hungary. He graduated as an engineer from the Budapest Technical University, and got his Masters in 1922. He got his first position at the Tungsram Co. From 1928, he worked for the Standard Co., where he became Technical Director in 1938. After WW II, he held different positions as head of microwave equipment research/develop establishments. From 1949, he became a lecturer and then, later on, a professor at different universities, such as the Technical University of Budapest. He got his doctoral degree in Technical Science in 1953. Dr. Istvánffy supervised the construction of the first powerful 120 kW broadcasting radio station in Hungary in 1933 (Figure 7). He played a significant role in the establishment of advanced Hungarian microwave technology. In his last 15 years, he focused his activities on problems related to antenna and other RF-component efficiency improvement, and on the education of the next engineering generation. Dr. Istvánffy died on the June 3, 1967, in Budapest.

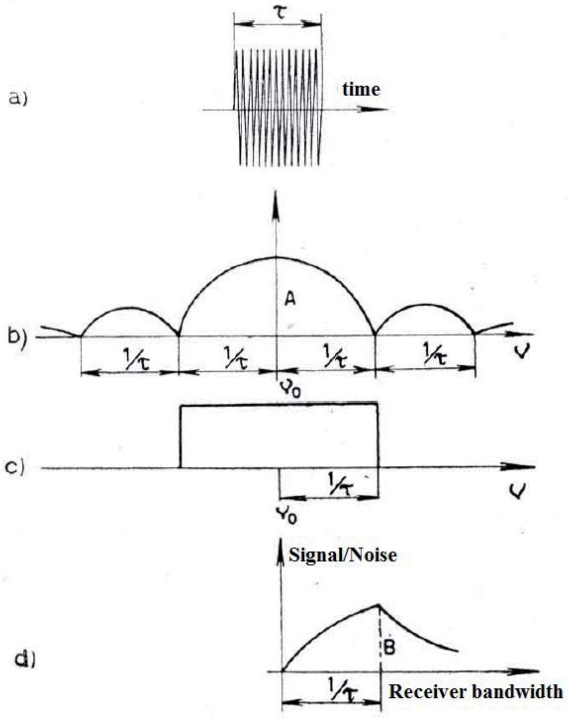


Figure 9. The pulse spectrum and matched filter as analyzed by Dr. Bay and his team [14].

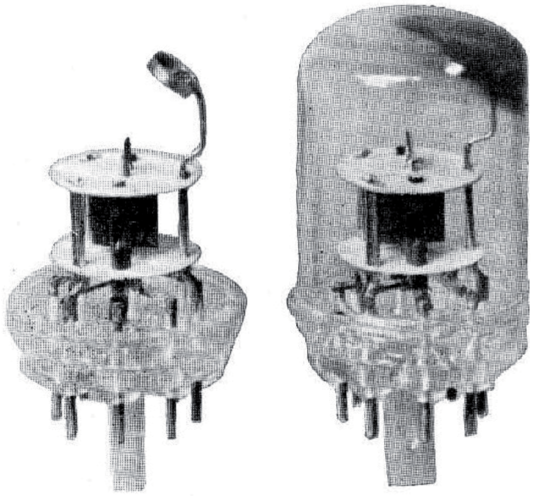


Figure 10. The EC 102 electron tube [13].

5. Development of the Requirements for Hungarian Radar

The literature on theoretical basics and technical achievements was available for Hungarian researchers and engineers until 1939. The work of James Clerk Maxwell, Heinrich Rudolf Hertz, Nikola Tesla, Guglielmo Marconi, Alexander Stepanovich Popov, and the patent of Christian Hülsmeyer were known. The Hungarian researchers were well aware of the theoretical basis underlying the physics of electromagnetic waves. In addition, they assumed that radars were built in strict secrecy in Germany, in the United Kingdom, in the USA and maybe in Italy, as well.

The Hungarian radios were world famous in the middle of the 1930s, proven by the fact that about 60% of the world's high-quality radio manufacturing was in the hands of Hungarian companies such as Orion, Tungsram, and Standard. Other companies, such as Philips and Telefunken, had special cooperation and interest in Hungary [12]. At that time, the Hungarian companies had permanent legal or RF-technology transfer cases with the biggest radio manufacturers, worldwide. In 1932, Tungsram started R&D activities in the field of television. They started cooperation with the Radio Corporation of America in 1938 (Figure 8). The Standard Co. had close connections with the International Telephone & Telegraph Co. After the bankruptcy of Ericsson in 1937, all its Hungarian properties and purchase requests became Standard properties [12]. Since 1928, all Hungarian Military

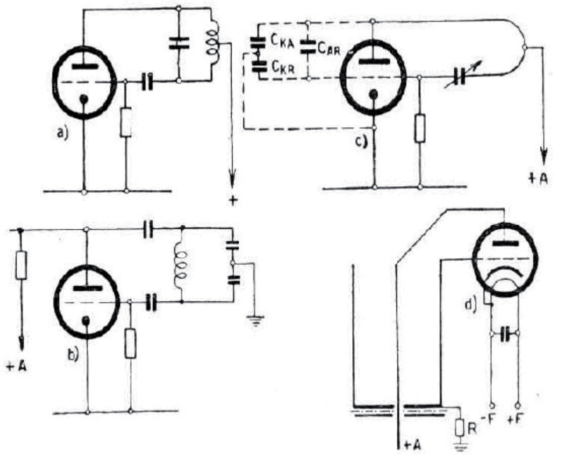


Figure 11. Different RF signal generators based on the EC 102 [13].

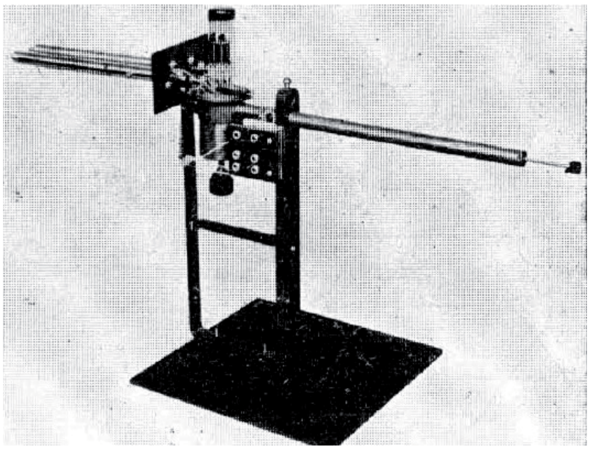


Figure 12. An experimental RF signal generator based on the EC 102 [13].

Radios were manufactured at Standard Co., supervised by Dr. Jáky's department at IMT. E. Winter, Dr. Szepesi, and A. Budincsevics developed a *mini RF tube* at the Tungsram Co. at the end of the 1930s for military radios, which was also used in radar applications. Dr. Bay and his team knew about the importance of the application for radar of the Barkhausen-Kurz reflex triode oscillator, the split-anode magnetron and Heil-oscillation, and the Klystron, which was limited to very low power at that time [13]. As Hungary gained top-level knowledge of electron-tube RF technology, and while the allocated time for R&D and manufacturing was short given the available engineering resources, the RF electron tubes were selected as key RF components for Hungarian radar.

Most likely, Dr. Bay got the preliminary research task from the IMT Department 4 to produce a survey for the development of a Hungarian radar prototype at the end of the 1930s. He and his colleagues knew the main challenges of radar equipment that had to be solved from the literature, and from their own ionospheric research. The first challenges mentioned by Dr. Bay were that the radar could be built only at RF frequencies higher than the commercial radio-broadcasting services used at that time [10]. His two main arguments were that the RF energy radiation and collection from a small spherical object could be more efficient at short wavelengths, and the modulation flexibilities–bandwidth allocation of the RF signal at shorter wavelengths – would increase.

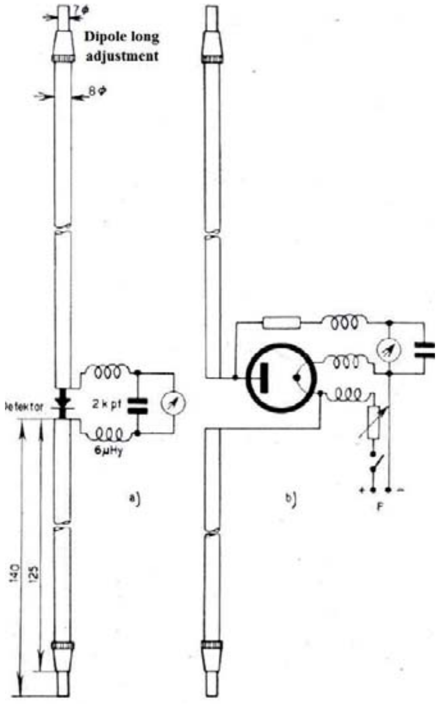


Figure 13. Variants of the measurement setup for measuring EME strength at a 50 cm wavelength [13]

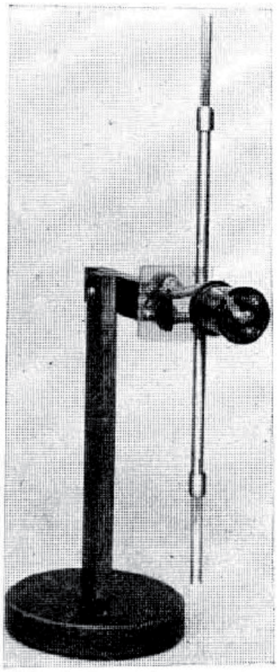


Figure 14. The realization of the EME measurement [13].

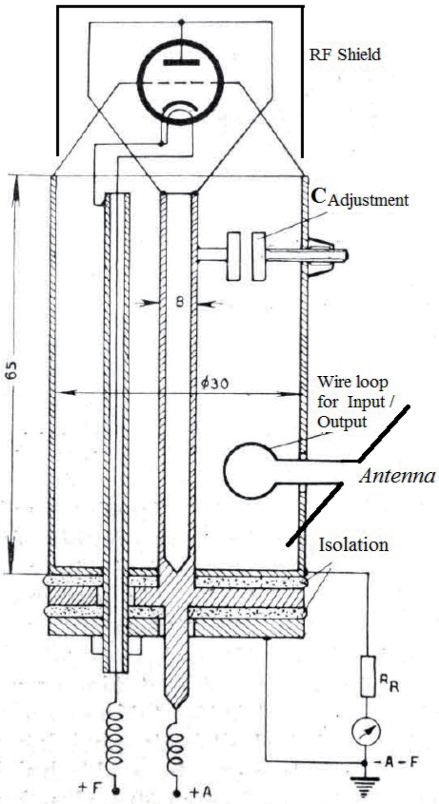


Figure 15. A cavity-resonator-based RF transmitter final amplifier with an antenna for a 50 cm wavelength [13].

From that moment, Dr. Bay's team's activities focused on uncertain factors of radar theory, such as RF signal excitation, RF signal propagation at higher frequencies, energy transmission, energy reflected from the collecting target surface, and improvement of the signal-to-noise ratio at the receiver's output.

We know that two modulation types for the radar application were analyzed by Bay's team. The first was the pulse modulation of radio waves used to measure the height of the ionosphere and to probe its interior layers, published by Gregory Breit and Merle Tuve in 1926. The second was the continuous-wave frequency-modulation method, used for the same aims as Breit and Tuve, published by E. V. Appleton and M. Barnett in 1925 [13].

The question was which modulation had advantages from the point of view of target detection, and which was the simplest in realization? Theoretical analyses were carried out by Dr. György Papp, Dr. Károly Simonyi [23], Dr. Antal Sólyi, and Dr. Zoltán Bay. Figure 9 shows a) the transmitted pulse, b) its Fourier spectrum, c) the simplified shape of the spectrum, and d) the signal-to-noise ratio at the output of the receiver as a function of the receiver's bandwidth.

After mathematical justification, they found that the (amplitude of the voltage) signal-to-noise ratio at the receiver output [14] was given by

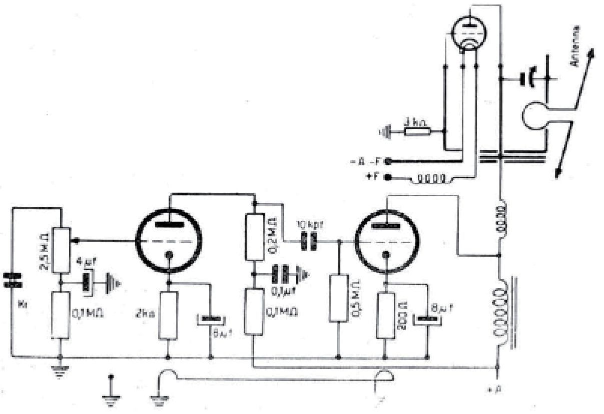


Figure 16. An RF transmitter final amplifier with an antenna for a 50 cm wavelength [13].

$$\frac{\text{signal}}{\text{noise}} = \frac{\chi}{\sqrt{4kTR}} V \sqrt{\tau}$$

where χ is a constant, including the radar cross section (RCS) of the target; R is the input resistance of the receiver (in practice, it was measured at the grid resistance of the electron tube); k is Boltzmann's constant; T is the receiver temperature (290 K); V is the transmitted pulse voltage; and τ is the transmitted pulse width.

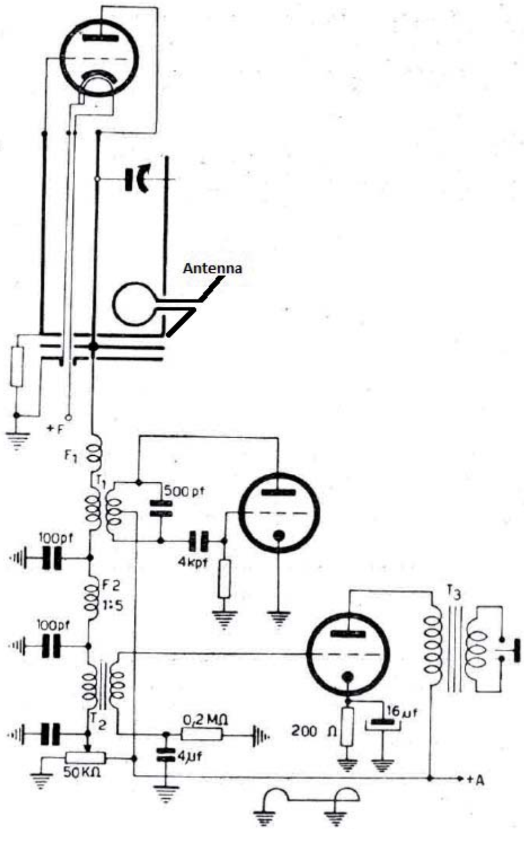


Figure 17. The circuit diagram of the communication test bed receiver for a 50 cm wavelength [13].

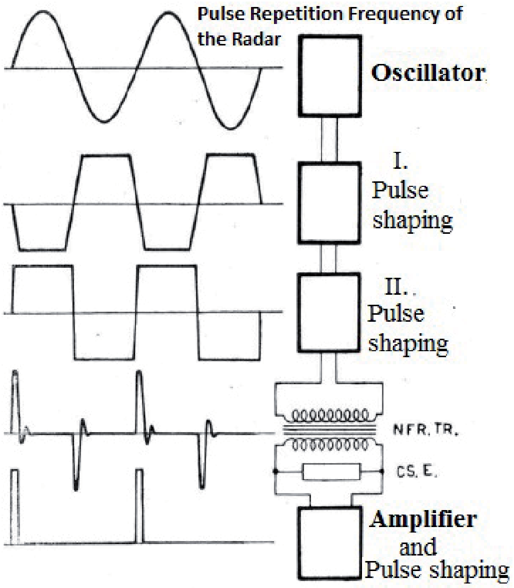


Figure 18. The RF pulse from pulse-repetition-frequency modulation [14].

This equation proved that target detection depended only on the *signal energy*. Subsequently, radar development based on continuous wave was dropped: the pulse technology was more familiar to them. A second conclusion of Dr. Bay was that the optimum bandwidth of the receiver was determined by the transmitter's pulse width.

The EC 102 tubes, manufactured by Tungsram Co., made it possible to do experiments and clarify some unknown questions related to the radar RF technology. The electron tube EC 102 with a 250 V anode voltage emitted 2 W power at a wavelength of 50 cm to 60 cm with 35% efficiency, while still working at 43 cm with 1 W. Figure 10 shows the EC 102 tube, while Figure 11 shows the connections for the signal generation. Figure 12 shows the full RF signal generator based on the EC 102 electron tube, which was used as a stable signal source generator for the experiments.

In building the equipment for transmission and reception of RF energy and its proper measurement peculiarities, the first steps to be solved concerned the development of test equipment. György Dallos carried out the required development. The antenna of the test system was the simplest part to be solved, since a half-wavelength dipole, 25 cm with 80 ohm radiation resistance, was very easy to balance. The electromagnetic energy (EME) was detected and measured with a crystal diode or a specially connected triode (see Figures 13 and 14).

Both the transmitter and the receiver used EC 102 tubes for simplicity (Figures 15-17). The first experiments were related to the determination of the signal-to-noise ratio, realized between Újpest and Vác, some 30 km apart, using less than 10 mW power. Having results on crystal-clear communication within the line of sight, it was possible to prove the theoretical calculations of the minimum detectable power required for target detection by experiment. The team assumed that the target was located at a 100 km distance from the radar, and that its surface reflected back 10% of the received energy. They assumed the receiver bandwidth was 10 kHz, and the receiver temperature was 290 K. Theoretical calculations showed that 50 mW power was enough for a 100 km communication range. This result was unusually small compared to the power of broadcast HF transmitters used at that time, but it was still 100 times larger than required for radar signal detection. The difference was explained by Dr. Bay as the higher signal-to-noise-ratio requirement for the crystal-clear radio communication than required for detection of the target echo with a signal-to-noise ratio equal to 10.

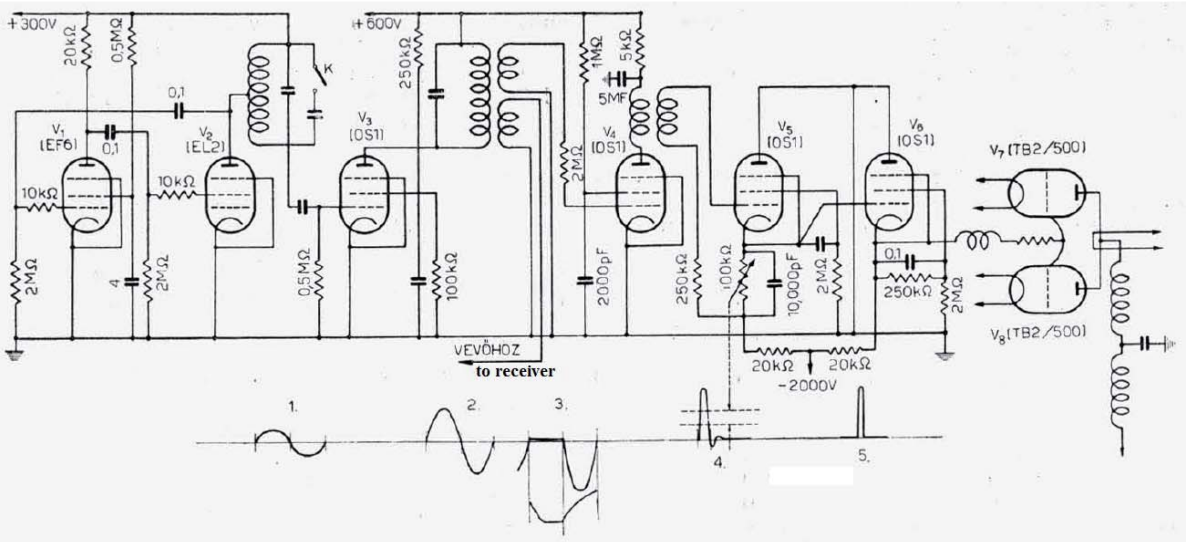
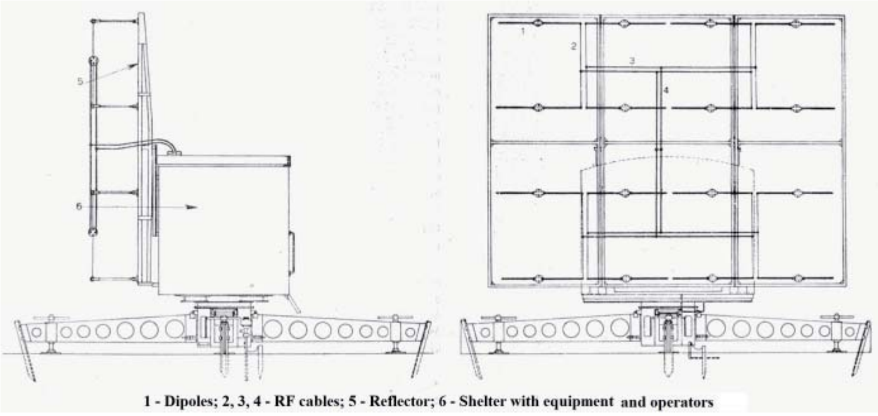


Figure 19. The transmitter exciter and modulator of the Sas (Eagle) air-surveillance radar [16].



1 - Dipoles; 2, 3, 4 - RF cables; 5 - Reflector; 6 - Shelter with equipment and operators

Figure 20. The Sas (Eagle) air-surveillance radar [15].

Using mobile receivers, atmospheric losses were determined under different weather conditions and environmental circumstances. Measurement results showed that the atmospheric losses were smaller at a 50 cm wavelength than in the HF band, and could be neglected. With further analyses and calculations of the 10 m^2 target, located at a 40 km distance, detection requirements for pulse radar were determined. Dr. Bay concluded that the radar parameters should be as follows: the transmitter wavelength was 50 cm; the parabolic antenna dish/reflector diameter was 3 m; the pulse repetition frequency was 4000 Hz; the pulse width was 1 µsec; and the transmitted peak power was 10 kW.

The next question to be solved was the RF signal pulse generation with the required pulse repetition frequency. Dr. György Papp, Dr. Zoltán Szepesi, and Antal Sólyi analyzed the advantages and shortcomings of the grid- and anode-controlled solutions. They found the grid-controlled case easier to realize, but that the reliability of the anode-controlled solution was higher. Figure 18 shows the pulse repetition frequency and the transmitter pulse generation method for Hungarian radars. This was a unique method compared to British or USA types of radar, which had separate modulators. Both the British and Hungarian solutions had advantages and disadvantages.

In parallel to this work, E. Winter and A. Budincsevics developed the EC-103 for 2.5 kW and the EC-108 for 12 kW peak powers for the 50 cm to 60 cm wavelength radars! The EC-108 electron tube was used for Borbála, Bagoly, and could also be used for the final amplifiers of the “Turul” radars.

The results were handed over to the Standard Co., Dr. Edvin Istvánffy’s industrial team, in order to develop radar devices for practice in October 1942.

6. Technical Performance of Hungarian Radars

The work order was so secret amongst the teams that even if somebody’s close colleagues knew each other’s studied problems, it was prohibited to be informed about the details. The only exception to this rule related to the team leaders. Dr. Edvin Istvánffy had done some preliminary preparatory work on radar subsystems, such as the transmitter and phased-array antenna designs, for the “m-” wave band.

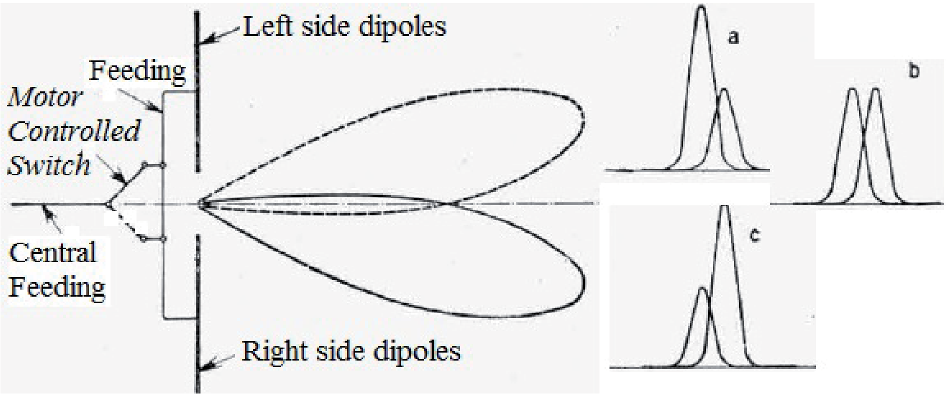


Figure 21. The “Monopulse” technique of the Sas (Eagle) air-surveillance radar [15].

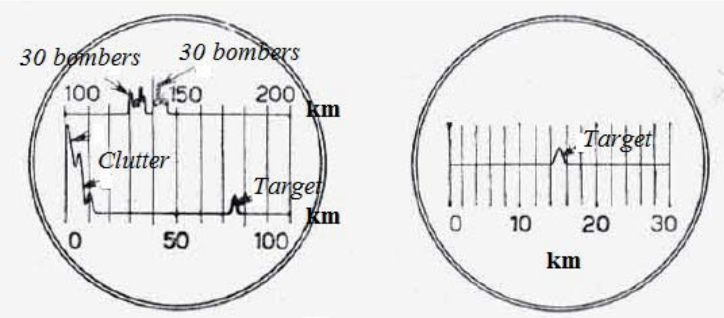


Figure 22. The "general and target-dedicated" indicators of the Sas (Eagle) air-surveillance radar [15].

6.1 Sas (Eagle) Air Surveillance Radar

The detailed theoretical requirements of the "Sas" radar were formulated by the team of Dr. Bay. The technical realization and manufacturing was solved by Dr. Istvánffy and his team. Here is a summary of the radar's technical performance:

- Operational frequency: around 121 MHz
- Maximum detection range above 200 km; required early warning range below 200 km
- Transmitter peak power: 20 kW
- Transmitter pulse width: 8 µsec (variable from 5 µsec to 50 µsec, *1 msec for moon radar*)
- Pulse repetition frequency: 750 Hz (about)
- Antenna: Horizontally polarized planar phased array with 16 parallel-feed dipoles, while the reflector size was 4 m × 5.3 m

Figure 19 shows the circuit diagram of the "Sas" radar transmitter-exciter. The 20 kW peak power produced by the TB2/500 transmitter electron tubes was connected in parallel with a 9000 V anode voltage and had a negative grid-control voltage. The high anode voltage caused sparking at the beginning, but this stopped when the burn-in process of the tubes and the power supply was modified for current limiting to avoid damage of the tubes in case of sparking. The pulse repetition frequency of 750 Hz was generated as in Figure 18. The transmitted pulse width was 8 µsec for normal air surveillance, and variable by potentiometer in position 4 of Figure 19 for sector searching or fighter control. A special output transformer produced the reference signal required for the heterodyne receiver.

The receiver's front end contained a spark gap for receiver protection, with a preamplifier. The EFF-50 mixer tube produced down conversion to 9.2 MHz, three tubes then amplified the signal, and subsequently a mixer for 3.2 MHz down conversion was followed by three tubes for signal

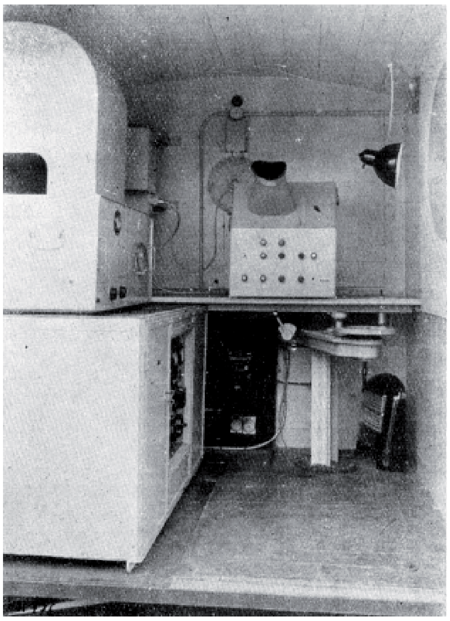


Figure 23. An inside-the-cabin view of the Sas No. 1 air-surveillance radar, equipped with one indicator [15].

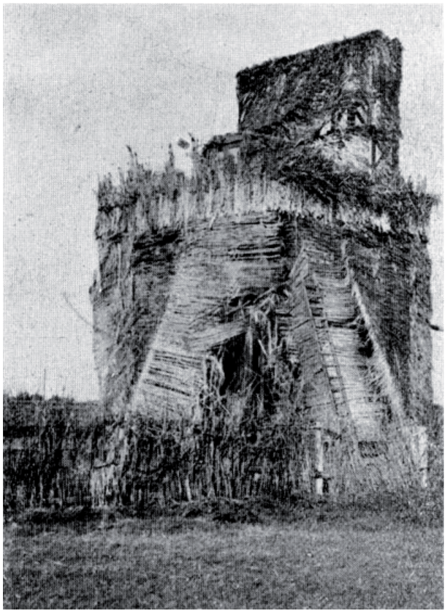


Figure 24. A covered Sas air-surveillance radar in operation [15].

amplification. The bandwidth of the receiver was optimal for an 8 μsec pulse, 200 kHz, as Dr. Bay's calculation for transmitter signal matching required.

The antenna system and the shelter with the equipment was modified a few times as operational requirements changed (Figure 20). The shelter with the antenna system, equipment, and operators rotated on its main axis. The horizontally polarized planar phased array contained $4 \times 4 = 16$ dipoles, with symmetrical feeding at the end of the neighbors' dipoles. The distances between neighboring dipoles were half a wavelength, while the distance between the dipoles and the aluminum reflector was a quarter wavelength. Horizontal polarization was chosen because observations showed that the horizontal size of the airplanes was six to eight times larger than the vertical size. The radar cross section (RCS) of the targets was therefore higher in horizontal polarization. The calculated half-power antenna radiation beamwidth was $\pm 9.5°$ in azimuth for common transmit-receive. In practice, the drop of the target power was very well detectable at ±5° off-boresight azimuth [15]. Targets at a distance of 100 km could be measured with a standard deviation of 1.7 km in azimuth. An improved azimuth-accuracy measurement technique was developed and implemented for the "Sas" radar, as Figure 21 shows.

Istvánffy wrote in [15] that "it was required to change the beam position of the planar array a few hundred times per second," and later on, he wrote about the pulse repetition frequency of 750 Hz. No more details are known today, but we hope a precise document will be found in the future. We imagine it was a special rotary-joint-like device, which had a small gap between the two halves of the antenna-feeding elements and the rotating arm sliding on the surface of the feeding-network connection. The sync motor switch, controlled by pulse-repetition-frequency pulses, changed the length of the feeding network, resulting in a phase shift to the left and to the right side, with half a pulse-repetition-frequency period to one side. This simple solution allowed moving the beam and the target positions in the second indicator, as is shown in the subfigures of Figure 21 labeled "a," "b," and "c." This type of "monopulse technique" allowed precisely measuring the target's position.

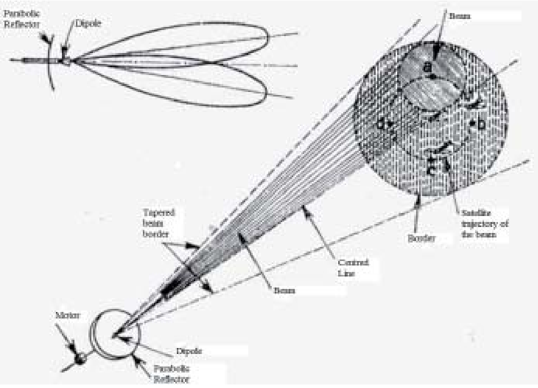


Figure 25. The "monopulse" technique of the "Borbála" fire-control radar [15].

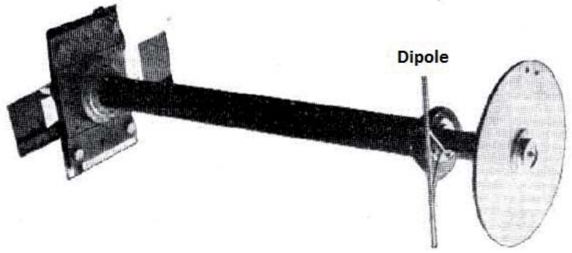


Figure 26. The "Borbála" rotating-dipole position and its armature [14].

However, the second "Sas" radar had already been produced with two target indicators supporting this idea, as Figure 22 shows. The first indicator was used for a general overview of the air picture, while the second indicator was used for fighter control. The first indicator showed different types of targets and clutter. It was mentioned in [15] that targets with a large RCS were frequently seen on the indicators at the beginning of the time line as second-time-around targets, and they could possibly be followed with the second indicator, which had a 30 km range and was positioned at the required distance.

Figure 23 shows an internal view of the "Sas" radar cabin. The largest part of the equipment was the power supply, located in the left bottom part, while the transmitter and receiver can be seen on top of the power supply. The indicator was in the middle, surrounded with communication and auxiliary equipment. Figure 24 shows the "Sas" #1 radar in operational position.

6.2 Borbála Fire-Guidance/ Control Radar

The category of the Borbála fire-guidance/control radar needs further clarification, because the radar was connected to the Juhász-Gamma target-position calculator for artillery usage. The Juhász-Gamma target-position calculator was separately developed. This analog computer continuously gave the target-position prediction for the air-

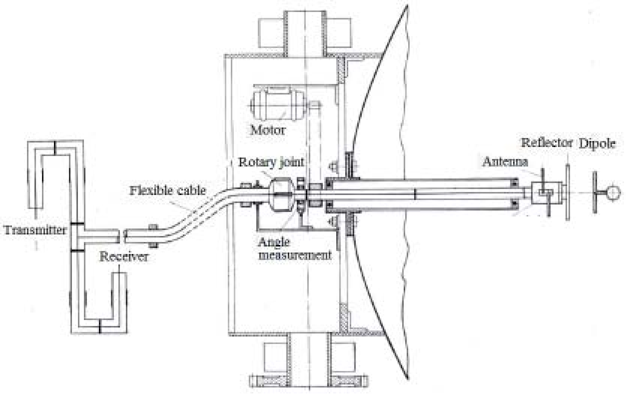


Figure 27. The Borbála antenna's armature, the rotating dipole, and auxiliary equipment [14].

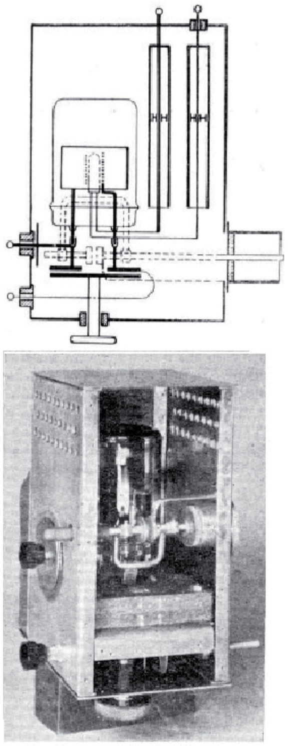


Figure 28. The connection and realization of the RF pulse oscillator of the Borbála radar [14].

defense guns. The Borbála radar and the Juhász-Gamma target-position calculator were connected for automatic control of air-defense guns in their usual operational mode. In the case where the input parameters of the Juhász-Gamma target-position calculator were of low quality, the Borbála radar could give fire guidance operating alone.

The detailed technical requirements of the Borbála radar were formulated by Dr. Bay's team. The technical realization and manufacturing were due to Dr. Istvánffy and

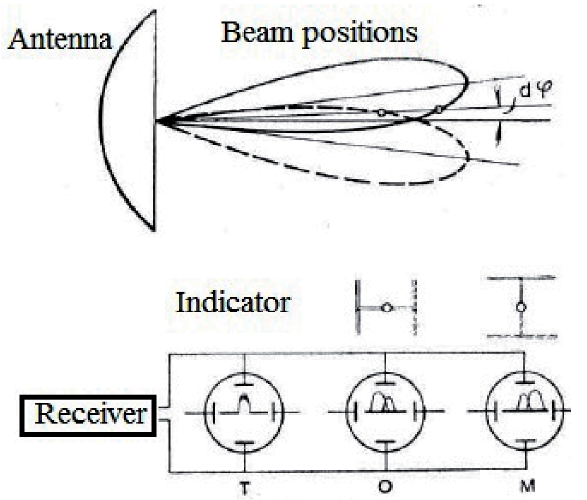


Figure 30. Target positioning in the indicators of the Borbála radar [14]

his team. Here is a short summary of the radar's technical performance:

- Operational frequency range: 500 MHz to 600 MHz (still operational at 700 MHz)
- Maximum detection range: 40 km; required fire-control range from 20 km
- Transmitter peak power: 10 kW
- Transmitter pulse width: 1 μsec
- Pulse repetition frequency: about 4000 Hz
- Diameter of the parabolic reflector: 3 m

The main challenge was the determination of the movement and position of the tapered (shaped) beam. During visits to Germany, Dr. Jáky had seen rotating dipoles on the Würzburg radar. The advantage of this solution for the target's angular-accuracy measurement became clear

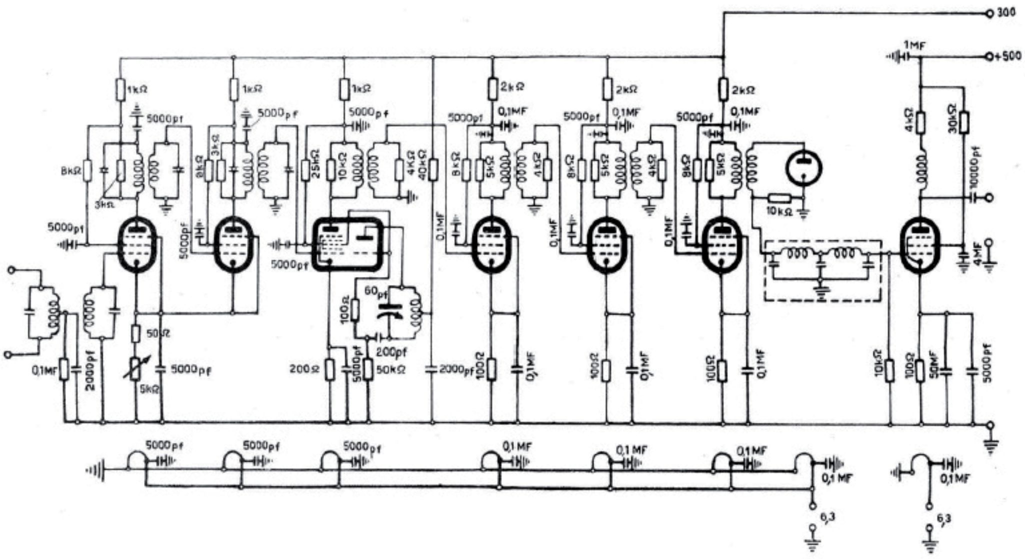


Figure 29. The receiver of the Borbála radar [14].

Figure 31. Antenna adjustment of the Borbála fire-control radar. Dr. Károly Simonyi is shown in front of the antenna [23].

to the Hungarian researchers. Figure 25 illustrates how the tapered beam of the Borbála fire-control radar moved in the case of two closely spaced targets. Figure 26 shows the Borbála rotating dipole's position and its armature. Dr. Istvánffy developed an electronic version of beam movements similar to those that were implemented for the "Sas" radar, but details of the implementation in the Borbála radar solution have not yet been found.

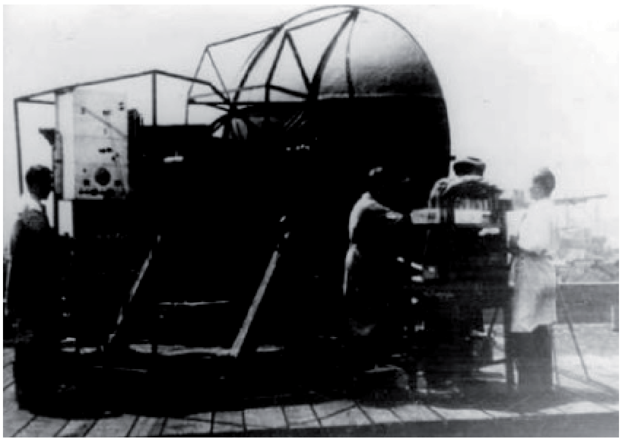


Figure 32. Testing and adjustment of the Borbála fire-control radar; Dr. Károly Simonyi is at right [23].

Figure 27 shows the detailed construction of the Borbála radar-antenna system. The dipole to the right of the reflector was required for beam-position calibration and adjustment. One of the most challenging tasks was for Dr. Bay's team to develop and implement a stable signal source. Figure 28 shows the connections, cavity resonator, and shielding of the Borbála radar RF pulse oscillator (left), developed by Dr. Zoltán Szepesi. It was constructed in the form shown at the bottom part of the picture.

Figure 29 shows the receiver details and the component connections of the Borbála radar. The main developer was György Dallos.

The "Borbála" radar receiver was based on Philips EFF 50 pentodes. The transmitter pulse width was 1 μsec, and as a consequence, the receiver required 1 MHz bandwidth, with very low noise and high-gain amplification.

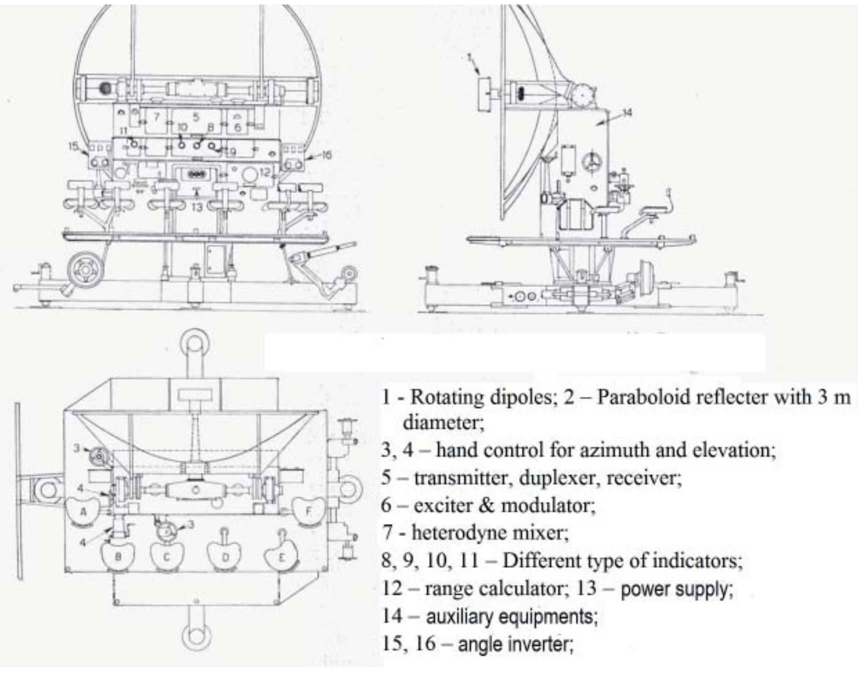


Figure 33. The Borbála fire-control radar on a mobile platform [14].

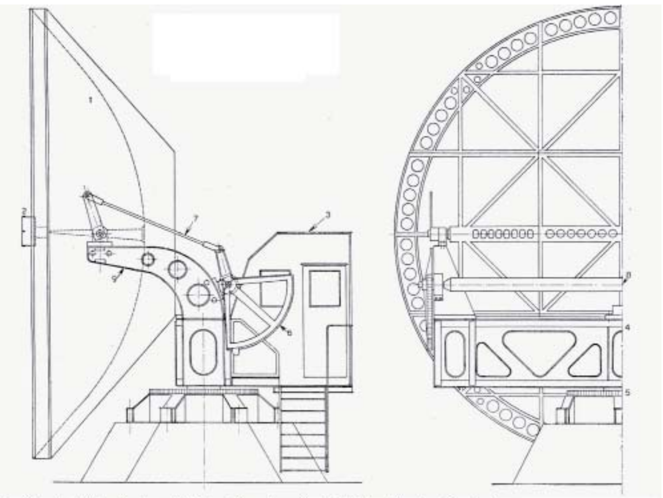


Figure 34. The 14-ton Bagoly (Owl) fighter-control radar [14].

The main issue was the double frequency conversion from 600 MHz down to 37.5 MHz, amplification, and then down conversion of the IF signal to 6 MHz, signal amplification, and detection. The local oscillator was stabilized with a cavity resonator at 250 MHz, but its working point was set on a higher harmonic to get the 37.5 MHz IF. The solution was developed by Lőrinc Vámbér.

Continuous operation of the "Borbála" radar with a pulse repetition frequency of 4000 Hz allowed measuring the target distance at 40 km with ±15 m theoretical precision, which could not be practically achieved, because the indicator resolution was 400 m. Special measures were required for expanding the indicator's resolution. The solution suggested by Dr. Bay allowed improving the determination of the angular position to close to the theoretical one, while all targets in the search volume were indicated relative to the center of the indicator. It was developed by Károly Simonyi, Kálmán Magó, and György Papp, and patented. Target positioning on the indicator is shown in Figure 30.

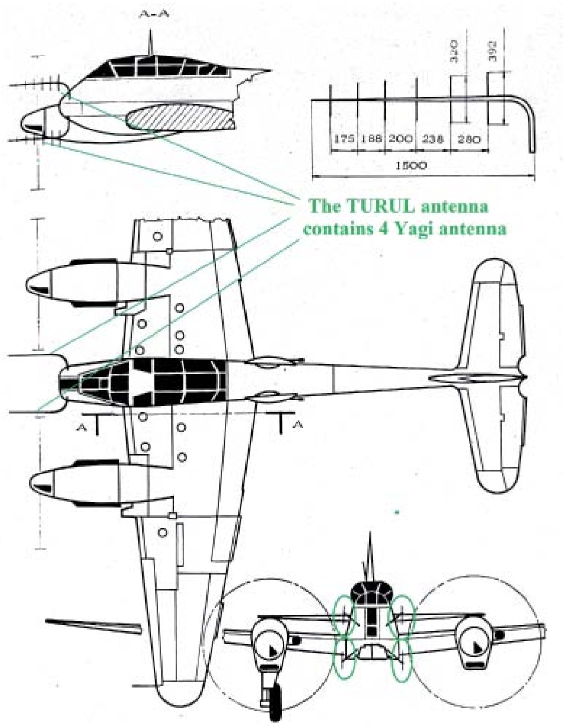


Figure 35. The Turul airborne radar [15].

Figure 31 shows the dipole positioning process in the antenna reflector.

The first experimental test of the Borbála prototype for echo detection of environmental objects and vessels on the river Duna was successful within an 18 km range on April 2, 1943. The picture in Figure 32 was taken at that time. Figure 33 gives an overview of the Borbála radar's main equipment's location, and the operator's position within the radar.

6.3 Bagoly (Owl) Fighter-Control Radar

The detailed technical requirements of the Bagoly radar were formulated by Dr. Bay's team. The technical realization and manufacturing were solved under the leadership of Dr. Istvánffy and his team, belonging to the Hungarian Optical Machinery Co. (hereafter called HOM), and the Bamart Co. Here is a summary of the radar's technical performance:

- Operational frequency range: 500 MHz to 600 MHz (still operational at 700 MHz)
- Detection range around 70 km
- Transmitter peak power: 10 kW
- Transmitter pulse width: 1 μsec
- Pulse repetition frequency: about 2000 Hz
- Diameter of the parabolic reflector: 7 m

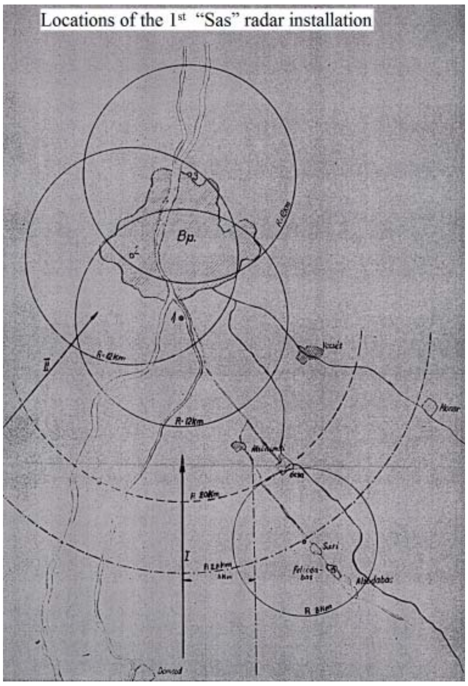


Figure 36. The locations of the first "Sas" radar installations (courtesy of *Haditechnika*).

The electrical parts of the technical challenges were solved during development and fabrication of the "Sas" and "Borbála" radars, but the mechanical construction required a professional in this field. Dr. Jáky tasked the RÁBA Automotive Group Co. and Machinery works Diósgyőr for development and installation of the 14 tons of construction armature. Figure 34 shows the construction of the radar.

6.4 Turul (Hungarian Mythological Bird) Airborne Radar

The detailed technical requirements of the "Turul" airborne radar were formulated by Dr. Bay's team. The technical realization and manufacturing were solved under Dr. Istvanffy's leadership, and his team belonged to Philips Hungary Co. Here is a short summary of the radar's technical performance:

- Operational frequency range: 500 MHz to 600 MHz (still operational at 700 MHz)
- Detection range around 6 km to 7 km
- Transmitter peak power: 1 kW to 2 kW?
- Transmitter pulse width: 1 µsec (variable)
- Pulse repetition frequency: 4000 Hz (about?)
- Antenna: four Yagi antennas on the nose of ME-210 Ca.

The electrical parts of the technical challenges were solved during development and fabrication of the "Sas" and "Borbála" radar. The main challenges were related to the installation peculiarities of the ME-210 fighter. Hungary procured licenses for the ME-210 for production, and the first airplane manufactured in the RÁBA Automotive Group Co. flew in March 1943. The prototype was tested, but disappeared with all related documents in 1944. Most likely, the management of Philips Hungary Co. put it in safe keeping. Figure 35 shows the construction of the Turul airborne radar. Most of the information related to this radar was based on [9].

7. The Situation at the End of WW II

7.1 Hungarian Radar Dislocation and Operational Uncertainties

The first installation of the "Sas" long-range air-surveillance radar on the top of the Jánoshegy mountain, within Budapest, produced catastrophic target-detection performance. The radar was installed close to the location

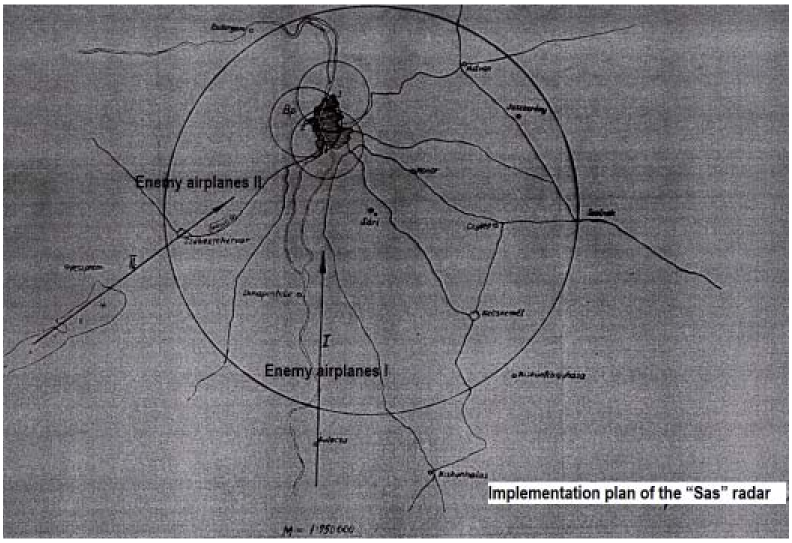


Figure 37. The implementation plan for the "Sas" radar (courtesy of *Haditechnika*).

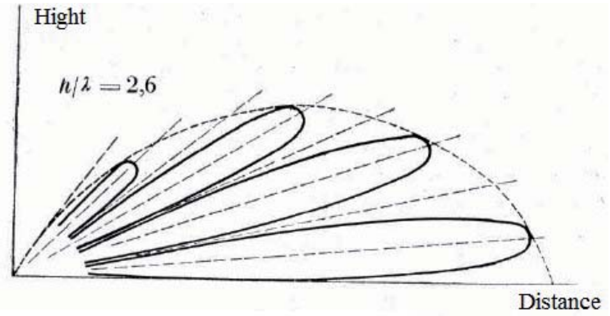


Figure 38. The vertical antenna pattern of the "m" (today called "VHF") band radar [16].

marked as "2" in Figure 36 in August 1943. Figure 36 shows three locations of the "Borbála" fire-control radar around Budapest. It has to be mentioned that the codename "Borbála" was used by the Hungarian Air Force for the Würzburg-D radar, procured and delivered in May 1943. At this time, the Hungarian-manufactured fire-control radar was not ready for military operation. A fully functioning signal network was built for the tests, for training the crew, and for the adjustment of local radar settings. Support of the Hungarian Air Force was requested and guaranteed. The "Sas" radar tests task list focused on the collection of data on the detection performance of the airplanes and the military operational usage, such as target allocation time and precision requirements determined by the operational possibilities of the air-defense guns. A high-priority task was to gather experience on how to select a radar site, on installation, and on operational and maintenance issues required for upgrade of the three other radars that were already being manufactured. A similar method was implemented for preparation of the manufacturing of the "Borbála" radar a few months later.

The Hungarian Air Force fighters flew flight paths determined by Dr. Jaky. The first flight path was planned for Budapest's airspace from a distance of 150 km at noon for two hours. The first measured observation indicated that the targets were detected and tracked at a range of 40 km to 100 km, while the detection differed over the time of day and the weather conditions. The experimental data collection continued until November 1943. It became clear that the Würzburg-D radars could not be supplied with precise and timely information on targets from this "Sas" radar position because the continuous efficient detection range was 12 km to 14 km in daytime, and 20 km to 25 km at night. The radar had an 8 km cone of silence in the middle of Budapest, dead zones, and unwanted reflections due to the Buda Mountains, while the Würzburg-D radars required at least a 20 km continuous track on approaching airplanes. These requirements could not be fulfilled from this position, as the flight paths of enemy airplanes approaching Budapest from the Duna valley and lake Balaton in Figures 36 and 37 show.

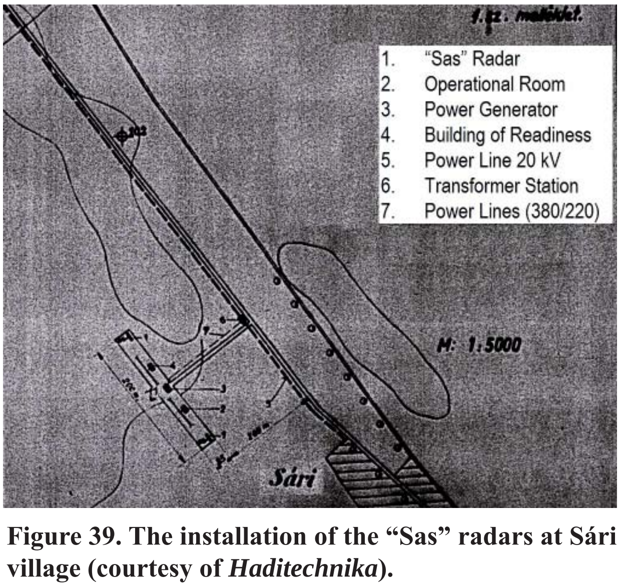


Figure 39. The installation of the "Sas" radars at Sári village (courtesy of *Haditechnika*).

Deeper analyses of the measurement results and calculations of Dr. Isvánffy on the "m"-band multipath observations indicated that reallocation of the radar required a flat surface, of which Hungary had a lot. Figure 38 shows the antenna's vertical pattern for the "m-" band radar, installed on a flat surface, published by Dr. Istvánffy [16]. The vertical antenna pattern had maximums and notches caused by multipath. They were calculated for the case of a ratio between the antenna's phase center to the wavelength equal to 2.6. Dr. Jaky's team found a suitable location for "Sas" systems far from high buildings and trees, north of the Sári village, 200 m from the main road. There were power lines in service, and it was easily accessed by train and vehicle. The radar operators and support teams could be quartered in good conditions. Last but not least, the radars and other equipment could be camouflaged as agricultural equipment. Figure 39 shows the first two Hungarian-manufactured "Sas" radar installations.

On December 20, 1943, the first two "Sas" Hungarian-built radars went into military operation. One of the radars was in permanent 360° azimuth air-surveillance mode. The second radar had a sector-search task on targets requiring more precise position and/or determination of the number of targets for fighter control or early warning. The military operational requirements and applications of the

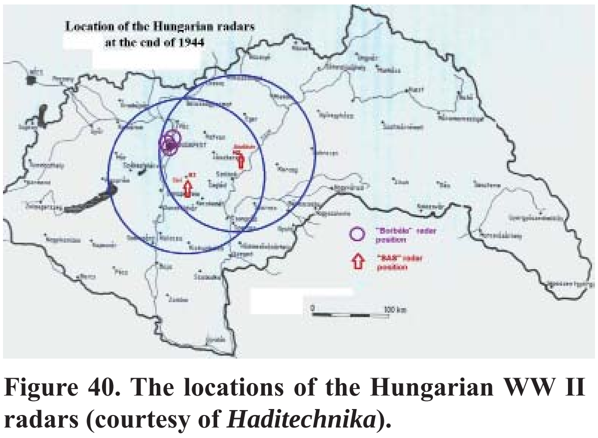


Figure 40. The locations of the Hungarian WW II radars (courtesy of *Haditechnika*).

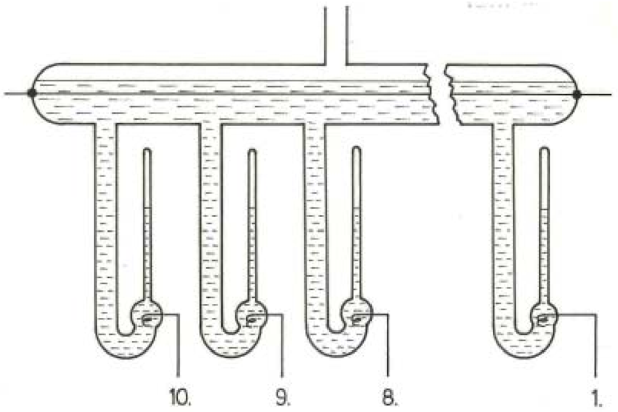


Figure 41. The first radar pulse integrator: the hydrogen coulometer (courtesy of Természet Világa).

Hungarian-made radars were very similar to the techniques applied by the German experts. It was planned for them to be operational, but no account has been found of the real operation of the Borbála and Bagoly radar installation for this radar site. A similar installation of "Sas" radars was in Jászkisér. From this moment, "Sas" air-surveillance radars sites played a significant role in Budapest's air-defense system.

Figure 40 shows the location of the Hungarian radars at the end of 1944. Four units of the "Sas" long-range air-surveillance radar and (with some uncertainty) four units of the Borbála fire-control radar were in military operational usage. They were elements of the air defense of Budapest. The Hungarian air-defense system, augmented by Hungarian surveillance and fire-control radars, efficiently destroyed the enemy aircraft, or the enemy was forced to use a high altitude. Bombing targets from high altitudes, such as South and North Railway Bridges located in Budapest, was not at all efficient. The fact was that more than 1000 bombs were dropped on each of both bridges, but only the North Bridge was hit by one bomb. Unfortunately, mass bombing caused many civilian casualties. After the occupation of Hungary by Germany, only the "Sas" radar locations were able to provide useful information to the Hungarian military leadership.

Four Borbála radars were manufactured to supply data for anti-aircraft artillery at the end of 1943. The first, the prototype of the Borbála radar, started an intensive series of tests in September 1943. Findings and new ideas for improvement were issued for the radars already in production. Production of the mobile-radar-platform turntables delayed the project until the first quarter of 1944. Statistics for the precise account of the Borbála military usage are not available today. After the occupation, there were no aircraft provided for adjustment of this radar for high altitude, and the manufacturer did not find the moral basis to finish the development.

The first two Bagoly radars were assembled at the premises of the Bamert factory in Újpest. At least one location was prepared in Sari, but presumably they also were not finished.

One Turul radar was built to be airborne equipment for fighter aircraft. Its prototype was built in an ME-210 Ca aircraft and was tested, but the work did not continue [9].

7.2 Political Uncertainties

On March 19, 1944, the Wehrmacht issued an occupation plan for Hungary, and deployed its own radar system within three weeks. Eight Freya air-surveillance radars, three Würzburg Riese radars, 50 mobile Würzburg-D radars with 88-mm air-defense guns, and 11 powerful radio stations were connected to the air-defense command center located in Budapest. The formation of a very curious and complex political situation could be observed in Hungary at that time. The government was changed to be in favor of the occupation forces. The resistance, markedly Endre Bajcsy-Zsilinszky (1886-1944), also started. Dr. Jáky, and most of the radar developers, became members of or were involved in the underground movement. Participation in Hungarian radar developments resulted in some temporal protection, but arrests started for different reasons. For example, Lipót Aschner (1872-1952), the General Director of the Tungsram company, was arrested and imprisoned. He received his freedom only after his company's subsidiary company, located in Switzerland, paid 100,000 Swiss Francs for his release.

Governor Horthy kept his position, and secretly started to collect forces that were required to stop war against the western alliance. The 1st Tank Regiment, which was eliminated during fighting on the eastern front in 1942-1943, was reformed, and equipped with the latest German Tiger and the newly developed heavy Hungarian "Toldi" tanks, and reallocated to villages around Budapest, in deep secrecy [17].

On July 5-6, 1944, Col. Ferenc Koszorús (1899-1974), commander of the 1st Tank Regiment, moved to the streets of Budapest on the order of Governor Horthy, and saved 363,000 Hungarian citizens from deportation [18]. As secretly formed forces became known, Hungary lost its strategic initiative. Since the rise of this movement, everybody in Hungary could be arrested at any time, such as Dr. Bay, who was arrested for a short time, and Dr. György Dallos, who died from torture at the end of 1944.

On October 15, 1944, Governor Horthy lost his symbolic position. Later on, General Gerhard Schmidhuber (Wehrmacht commanding officer in Budapest) saved some 60,000 to 70,000 inhabitants of Budapest from liquidation, including radar developers and manufacturers.

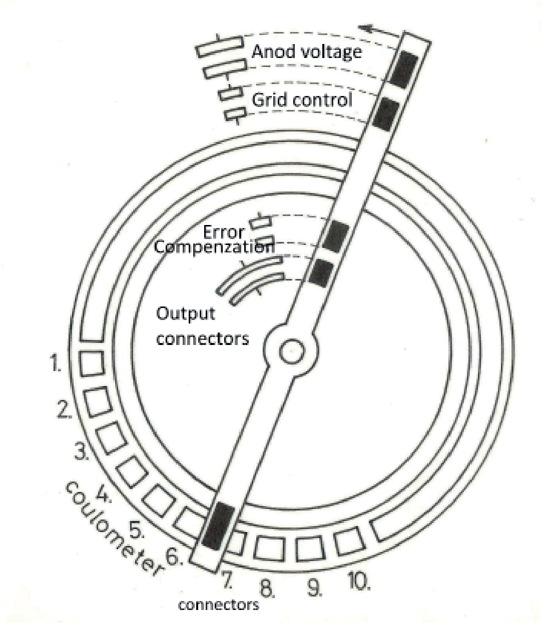


Figure 42. The control device for the hydrogen coulometer (courtesy of Természet Világa).

7.3 Other Radar-Related "Exotic" Projects at This Time

In addition to the radar projects, several "exotic" development topics were launched at the IMT. The organizer was Dr. Jáky, in cooperation with the Standard Co., Tungsram Co., and HOM firms. After the occupation of Hungary, these projects lost their importance for Hungarian developers, manufacturers, and these projects were even frequently sabotaged. Today, we know that Dr. Jáky's team was part of the resistance movement. As such, Dr. Jáky's department started to build high-power VHF radios using different radar components. These radios were aimed at connecting the resistance leadership with the western alliances.

Sometimes, the radar developers did not understand each other's initiatives and movements. One example was where Dr. Jáky came into conflict with another genial engineer developer, Kálmán Tihanyi (1897-1947). Kálmán Tihanyi was the greatest ground breaker of television engineering and the inventor of the iconoscope. He repatriated before the war, and launched an ambitious project to develop an ultrasound weapon with the code-name "Titan." The essence of the weapon was the projection of an amplified sound effect, which created a series of detonations. It was focused by parabolic mirrors in the required direction. According to the principles of military developmental activities at that time, Tihanyi and his development team would have worked under the supervision of the IMT. However, Tihanyi was worried about his invention, on the one hand, and was even more afraid having his invention taken by unauthorized (German) hands, on the other. Having taken advantage of good contacts with Governor Horthy, he was exempted from being supervised by the IMT, which Dr. Jáky had tried to press on him several times, with no success. After the occupation of Hungary by German forces, Tihanyi sabotaged the creation of the weapon. Development of the "Titan" came to a standstill at 80% completion. Tihanyi was arrested, and survived WW II [7].

Another "exotic" topic was "the remote control of flying bombs." In August of 1944, at a discussion held and recorded in Dr. Jáky's office, the fiasco of the traditional anti-aircraft artillery was mentioned. Reference [11] describes the tests of a prototype of a surface-to-air missile that was planned. Dr. Edvin Istvánffy, on Standard's part, Director General Grosh, and senior counselor Dr. Vágó, on HOM's part, did not report any technical difficulty, and no financial problems arose. The remote-control system was under development in the HOM and Standard firms, while the rocket was to be designed at the IMT. The expected operational range was 10 km to 20 km. About 40 missiles were manufactured and used in the defense of Budapest without proper remote-control electronics.

At the end of 1944, Budapest was under intensive air attacks that destroyed the capital, and caused lots of civilian casualties. Dr. Jáky's house was ruined while nobody was at home. His family moved to the IMT territory, known as the safest in Budapest. In January of 1945, during a Soviet air attack, a bomb burst through the roof of the IMT building, and it exploded in the basement. Among the dead were Dr. Jáky, his wife, and their two daughters, and staff engineer Colonel Béla Cserneczky (1898-1945). Only his youngest daughter survived. With his death, the community of Hungarian military radar and radio communications lost one of the greatest technical leaders of its heroic era [11].

8. Measurement of Earth-to-Moon Distance

It was well known at that time that Dr. Bay examined microwave propagation in the atmosphere and reflections from the ionosphere. His dream since his childhood was to measure the Earth-to-moon distance. After the German

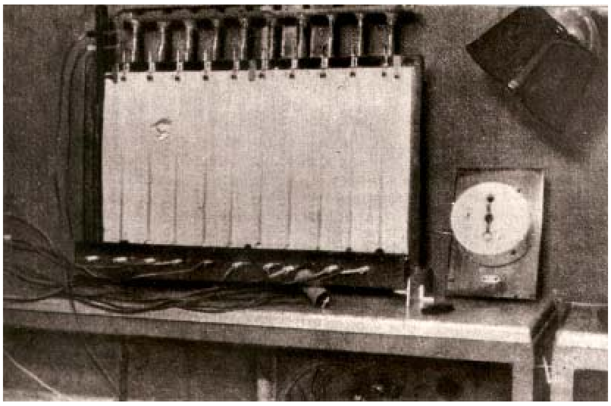


Figure 43. The realization of the hydrogen coulometer (courtesy of Természet Világa).

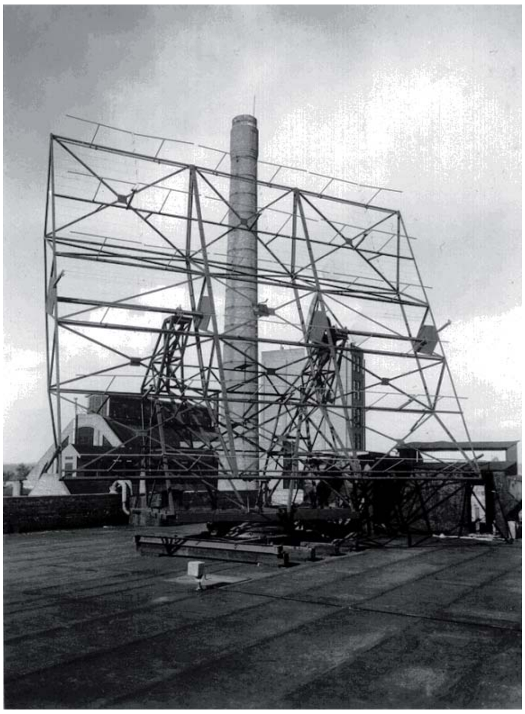


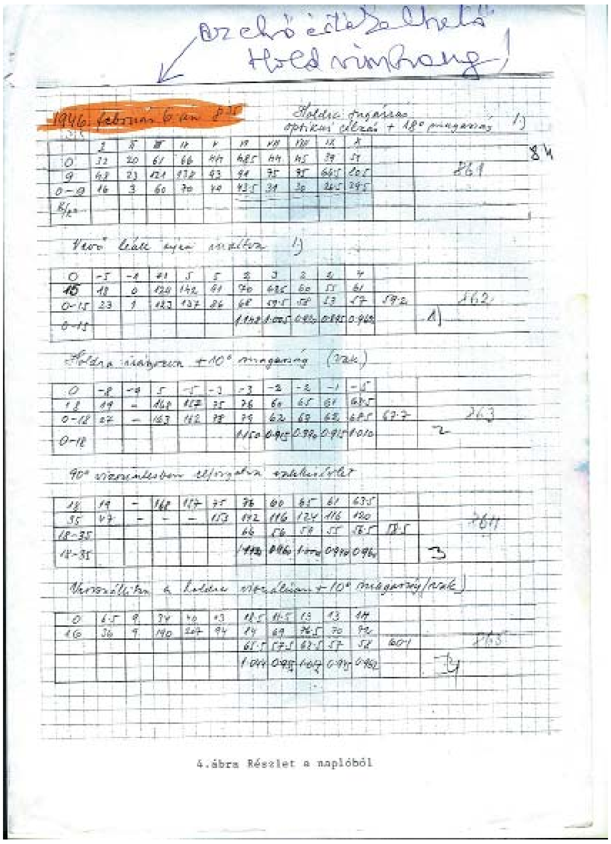
Figure 44. The planar phased-array antenna of the moon radar, size 6×8 m, with 36 dipoles (courtesy of Pál Szabó) [5].

Figure 45. The moon radar antenna on the roof of the Standard Co. (courtesy of Pál Szabó) [5].

occupation, most of the Hungarian radar developers lost their enthusiasm to be successful in developing military technology. As the situation in the country deteriorated more and more, everyone tried to save themselves, their colleges, and the property of factories, labs, and institutes. In this atmosphere, Dr. Bay suggested measuring the Earth-to-moon distance using radar. This task was not only accepted but supported by Engineer-Colonel Dr. József Jáky, national coordinator of radar manufacturing. Dr. Bay and his team moved to Nógrádverőce (not so far from Budapest) to develop the theory required, and carried out experiments in April 1943. They had a "Borbála" radar installed there. Calculations to get echoes from the moon were carried out for this radar. At that time, the following uncertainties had to be clarified, and the theories for solving them developed:

- Could 0.5 m microwaves penetrate through the ionosphere?
- What was the radar cross section of the moon?
- Was the reflectivity factor of the surface of the moon similar to the Earth, that is, about 10%?
- How could the required minimum detectable signal level at the output of the radar receiver be achieved?

The moon is about 380,000 km away from the Earth, and the signal strength decreases with the fourth power of the distance. Dr. Istvánffy analyzed the moon's radar cross section with a method of calculation that was different from that introduced in the West, the Fresnel-zone-based method. Both methods proved that the moon was a point target from the measurement point of view. The moon's movement caused a Doppler shift of the RF signal. It was required to apply filters with a 30 Hz bandwidth, which were not possible to develop in Hungary from a financial point of view. The calculated minimum required signal-to-noise ratio at the output of the radar receiver was at least 100 times higher than Hungarian scientists were able to produce with the modified



Az echó észlelhető Hold visszhang!

1946. február 6-án

4.ábra Részlet a naplóból

Figure 46. A photo on the successful measurement test minutes (courtesy of Pál Szabó) [5].

Figure 47. Dr. Bay presenting the moon measurement (courtesy of Pál Szabó) [5].

Borbála radar. To cover the energy gap, Dr. Bay suggested an idea of sending repeated signals, and integrating them on receiving before the detection. The radar pulses need 2.5 seconds to travel the Earth-moon-Earth distance. The scientists calculated a 50-minute period for transmitting 1000 pulses, integrating them every three seconds, and finally detecting the moon's reflected signal. Radar-pulse integration had not yet been invented. The solution was suggested by Andor Budincsevics (1905-1995) and Emil Várbíró (1908-1977?), János Patak, and János Pintér, who built the test equipment. They developed a device called a hydrogen coulometer, shown in Figure 41. This generated hydrogen gas in the channel-dedicated distance/range cell where the radar pulses were received. The dedicated range cell was selected with the coulometer control device shown in Figure 42. The calculation indicated that the signal-to-noise ratio would be improved about 30 times, because the hydrogen level produced from noise only was distributed over all lags of the hydrogen coulometer, while the radar pulses produced hydrogen only in the moon-range-related lag of the coulometer. Figure 43 shows a photo of the hydrogen coulometer.

Besides the actual moon radar experiment, blind tests were conducted in order to get reference measurements for free space, and to estimate the noise level of free space. The first trials with a modified Borbála radar and its 3 m (10 ft) parabolic-dish antenna had no success, most likely because the power supply of the radar was frequently interrupted. The scientists moved back to Tungsram Co. in autumn 1944.

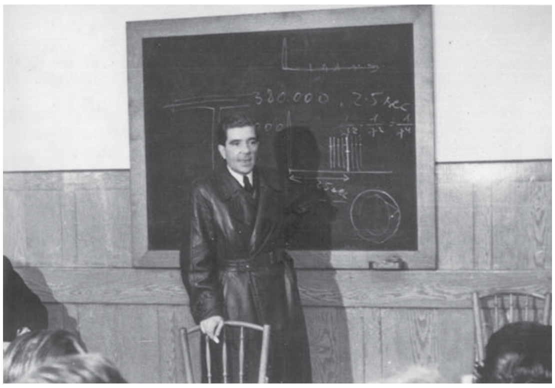


Figure 48. Dr. Bay presenting the moon measurement in 1946 (courtesy of Pál Szabó) [5].

At the end of the war, the appearance of the living conditions for Hungarians and Europeans was not like a Hollywood show for New Yorkers. Budapest was in ruins, most of the Hungarian territory was controlled by local militias, and occupation forces started sacking the country. In this atmosphere, Dr. Bay reinitiated a project for a measuring the distance to the moon [19]. He requested and got support from his former colleagues in radar development, and from the Hungarian Academy of Science. The new trials started in July 1945, with the remainders of the "Sas" long-range air-surveillance radar. Dr. Istvánffy modified the "Sas" radar platform to make the antenna beam steerable, not only in azimuth, but in elevation, too. The antenna increased in size to 6 × 8 m, with 36 dipoles, and was installed on the roof of the Standard Co. as shown in Figures 44 and 45. The rest of the measurement setup was the same as was used during previous trials in Nógrádverőce, with improved special narrowband receiver filters designed by István Barta. Lajos Takács and Tibor Horváth calculated the moon's position, Dr. Papp and Dr. Simonyi were responsible for tests, while Jenő Pócza, Zalán Bodó, Jenő Csiki, and László Tary contributed to "Sas" radar modification developments, and carried out the measurements.

On February 6, 1946, the accumulating coulometer showed a signal of 4% above noise level. Figure 46 shows the picture with the minutes of the successful measurement. Dr. Bay and his colleagues considered this high enough to call it a success. Figures 47 and 48 show Dr. Bay during the presentation of the measurement success [5]. Figure 49 shows the moon radar receiver and coulometer in the laboratory, with Dr. Bay in the middle.

A few weeks earlier, the US Diana project had a "touch" of the moon's surface using radar. However, the method used by Dr. Bay's team was more advanced, as it was the first time in history that radar-pulse integration was invented and applied for radar measurement. At that moment, radio astronomy opened a new era of scientific thinking and experimenting of the cosmos.

8.1 Performance Comparison of Hungarian-Produced Radars with Other WW II Radars

After WW II, Edvin Istvánffy compared the technical performance of the "Sas" air-surveillance radar with other radars that played a significant role on the WW II battlefields [16]. The maximum detection range, D_m in Table 2, was calculated for a 10 m^2 target in free-space conditions. The "Würzburg Riese" radar's maximum detection range was 2.6 times larger than the small "Würzburg" radar's detection range [20]. Dr. Istvánffy applied the following equations for the calculations [16]:

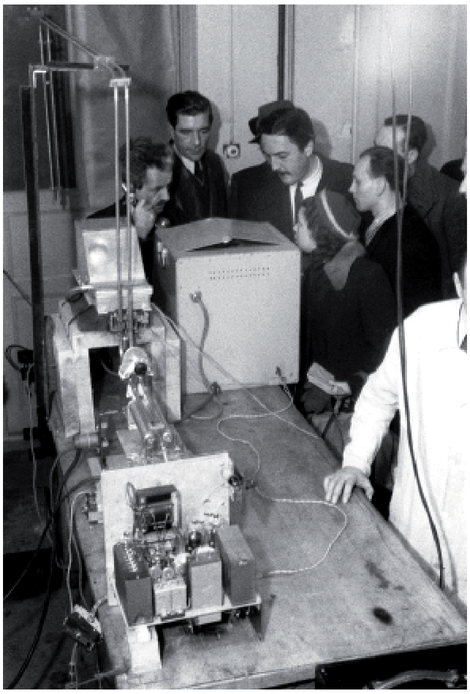


Figure 49. The moon radar receiver and coulometer in the laboratory, with Dr. Bay in the middle (courtesy of Pál Szabó) [5].

$$D_{sz} = \sqrt[4]{\frac{A_e}{4\pi}\frac{P_a}{P_{min}}}\sqrt{\frac{G\lambda}{4\pi}} \ ,$$

$$P_{min} = \frac{V_z^2}{4R} = kT\Delta f \ ,$$

$$\frac{P_a}{P_{min}} = \frac{P_a}{kT\Delta f} = \frac{E_a}{kT\Delta f \tau} \ ,$$

$$E_a = P_a \tau \text{ Joule,}$$

Figure 50. The "LRB-T1" fire-control radar in operational position (courtesy of *Haditechnika*).

where A_e is the radar cross section, using a Liberator type with $10\,\mathrm{m}^2$ for calculations; P_{min} is the minimum detectable signal for the case when the signal-to-noise ratio is equal to one and the noise contains only Johnson noise; P_a is the transmitted peak power; and G is the antenna gain (transmitting equal to receiving). There are documents [4, 5] that mention that the "Sas" radar detected targets "at 500 km distances in special propagation conditions." These "rumors" were analyzed by authors to prove or disprove the claims. We carried out a simulation, applying the "Sas" radar technical parameters to the Blake chart. We determined that the free-space detection of the "Liberator" type target, with a radar cross section of $10\,\mathrm{m}^2$, and the "Sas" radar performance of Table 1, could be proven. For our calculation, we used $P_d = 0.5$ and $P_{fa} = 10^{-6}$, with the Swerling Case 1 fluctuation model, a single-pulse signal-to-noise ratio of 18.93 (12.77 dB), an antenna half-power beamwidth of 18°, and with the antenna rotating at three revolutions per minute. If the pattern propagation factor was chosen as 1.74 (which was still very common for a properly selected VHF-band radar installation), the target-detection range increased to 231 km (125 nmi). Details of the calculation are available from the authors.

Figure 39 shows two "Sas" radars installed in quasi-monostatic configuration, where the radars are 200 m from each other. The term bistatic radar was first coined by K. M. Siegel and R. E. Machol in 1952 (K. M. Siegel, "Bistatic Radars and Forward Scattering," Proceedings of the National Conference of Aeronautical Electronics, May 12-14, 1958, pp. 286-290 [21]). The requirements of quasi-monostatic radars are that the bistatic angle between radars be very small, i.e., less than 3°, and that the radars use the same carrier frequency, modulation, and pulse-repetition frequency, with proper triggering. Such radar systems were in operation in Hungary. Further information on the subject can be found in [22].

Among the many advantages of the quasi-monostatic configuration application shown in Figure 39, one is that the two "Sas" radar antennas searched the same azimuth sector three times per minute. In this case, the transmitted powers of "Sas1" and "Sas2" were added on the surface of the target, the received antenna gains were added, while twice the pulse-repetition-frequency-determined number of pulses could be observed on the indicators. Both radar pulses hit the target, or clutter, and selected, amplified by each other's antennas and receivers, while the received signal pulses were observable on each other's indicators. In this case, the target-detection performance increased by +3 dB transmitted power, +3 dB received antenna gain, and +3 dB signal integration, resulting in a sum of 9 dB. The normal target-detection range was therefore increased to 384 km (207 nmi) for targets with a radar cross section of $10\,\mathrm{m}^2$. The detection performance of the "Sas" radars did not depend on special propagation conditions. The only issues here for us were the most likely unsynchronized transmitter triggering, and the unknown system losses. Our

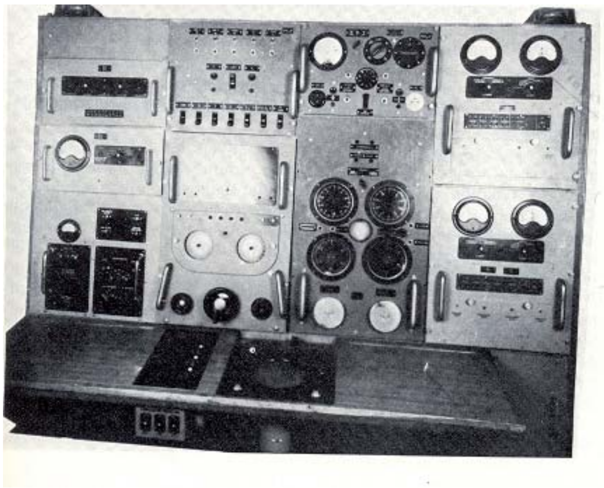


Figure 51. The "LRB-T1" fire-control radar indicator and control station (courtesy of *Haditechnika*).

experience shows that the slightly different pulse repetition frequencies, within 3 Hz, allowed exploitation of the quasi-monostatic operation with increased losses. These cases gave a good opportunity to detect targets, 30 bombers, at 500 km range, or to see the clutter returns from the Alps Mountains, as military reports indicated.

9. The End of Hungarian Radar Manufacturing

At the end of 1950, the Hungarian Army was already equipped with military weapons manufactured by the former Soviet Union, remaining from WW II. Radars were found missing on the lists of product names. The IMT got the task of creating a separate department, dedicated to radar developments, and of establishing a "Radar Committee" responsible for new Hungarian radar developments. The "Radar Committee" consisted of the best experts on RF technology at that time. Without attempting to be comprehensive, we mention some names: Dr. György Almásy (1919-1984), Dr. Edvin Istvánffy (1895-1967), Dr. István Barta (1910-1978), Dr. Géza Bognár (1909-1987), Ferenc Bajáki, Dr. András Dallos, Dr. Albert Korodi (1898-1995), Dr. György Mezei, István Nyári, Dr. Jenő Pócza (1915-1975), Dr. Tamás Sárkány (1925-2012), Dr. Nándor Szabó, Dr. Rezső Tarján (1908-1978), and Dr. Ernő Winter (1897-1971).

The expertise for construction of long-range air-surveillance and fire-control radars still remained. Requirements were settled to be better in performance than the USA SCR-584 fire-control radar. A prototype radar was developed and assembled with the name LRB-T1 at Gamma Technical Co. and HOM. Subsystems of the radar were developed and manufactured in facilities of Tungsram, Orion, Standard, Telefongyar and Ikarusz. Figure 50 shows the fire-control radar in its operational position, while Figure 51 shows the "LRB-T1" fire-control radar indicator and control station. The following is a summary of the LRB-T1 fire-control radar technical performance:

- Operational frequency: around 3 GHz (magnetron dependent)
- Detection range around 100 km, automatic target tracking up to 70 km
- Transmitter peak power: 250 kW
- Transmitter pulse width: 0.8 μsec
- Pulse repetition frequency: around 1000 Hz

The prototype was built with an original USA 2J32-type magnetron, because Hungary was not manufacturing magnetrons at that time. The power supply of the radar

Table 2. A comparison of "Sas" radar performance with other WW II radars 16].

Type	λ m	P_a kW	τ μsec	E_a joule	G	Δf MHz	$\tau\Delta f$	Z	PRF Hz	L	D_m km
"Sas" air surveillance	2.5	20	8	0.16	59	0.2	1.6	12	750	1.3	135
"SCR-588" air surveillance	1.44	125	2.5	0.31	210	0.74	1.85	16	400	1.76	160
"SCR-584" air surveillance & fire control	0.1	300	0.8	0.24	2300	1.7	1.36	31.5	1707	1	140
"AN/MPG-1" fire control	0.03	60	1/0.25	0.06	12000	10	10/2.5	50	1024	1.17	64
"Würzburg"	0.54	7	2	0.014	230	0.5	1	107	3750	0.76	42

Note: λ is wavelength; P_a is transmitter peak power; τ is transmitted pulse width; E_a is energy; G is the gain compared to an isotropic antenna; Δf is the receiver bandwidth; Z is the noise figure; PRF is the pulse repetition frequency; L is the indicator losses.

worked on 500 Hz, which allowed constructing a smaller and more compact transformer than is usual for systems built with the common 50 Hz. The prototype introduced to the Hungarian Government and Communist Party was representative of the IMT firing-test range, and was located at the village of Táborfalva in 1951. The "LRB-T1" fire-control radar was connected to an upgraded version of the Juhász-Gamma target-position calculator for artillery usage. The maneuvering fighter was locked onto and precisely followed with the "LRB-T1" fire-control radar within 70 km range. After successful demonstration of the technical and military operational performance, 10 new modernized versions of the "LRB-T1" fire-control radar, such as "LRB-T2" and "LRB-T21," were ordered and delivered to the Hungarian Air Defense Forces.

The "LRB-T1" radar technical performance was compared with the original USA-produced SCR-584 fire-control radar as a reference, and with the former-Soviet-Union-manufactured SZON-4 radar, during special test trials where the targets were flying and maneuvering at altitudes of 1000 m, 2000 m, and 4000 m. The test results focused on the static and dynamic errors of the target-position measurements and speed calculations. The "LRB-T1" radar technical performance fulfilled all requirements, while the SZON-4 failed. At that time, the "LRB-T1" radar was completely manufactured in Hungary. Both the SZON-4 and the SCR-584 had a weight of 16.5 tons, compared to 7.5 tons for the "LRB-T1." The part numbers of the resistors of the SZON-4 subsystems were exactly the same as for the SCR-584.

Political decisions included the harmonization of the weapon systems of Hungary and the former Soviet Union, and required stopping any Hungarian radar development. The "LRB-T1" radar manufacturing was changed into SZON-4 production; this also stopped in 1957. Finally, all Hungarian radar research, development, and manufacturing drawings, documentation, technical manuals, and test minutes were collected and destroyed in 1958.

10. Conclusion

This paper sought to highlight the importance – not only from a Hungarian radar-system-development point of view – of topics related to radar and microwave technology research, radar manufacturing, and its military applications, from the period of the 1940s to mid-1950s. This was a period when Hungarian radar developers, Dr. Zoltán Bay, Dr. Edvin Istvánffy, and their teams, were in a unique situation under the leadership of the Institute of Military Technology and Dr. József Jáky.

The conditions were very frustrating at that time. The Hungarian elite was not able to defend Prime Minister Pál Teleki, and could not keep our country independent. The Hungarian Home Defense Forces were small, and modernization was delayed. At that time, the modernization of military radar systems was one of the most urgent tasks, but our ally made it quite clear that Germany would not supply Hungary either with radar nor with technical assistance.

In accomplishing these tasks, the Hungarian experts were forced to find out how the newly required radar systems worked from theoretical and system philosophical points of view, and how to develop and manufacture radars. Within two years, 11 radars were researched, developed, prototyped, and manufactured: four surveillance, four fire control, two fighter control, and one airborne prototype.

Dr. Bay and his team invented or reinvented the matched filter for the pulse radar; the radar receiver characterized with minimal noise figure; the widely used cavity resonator as a high-quality filter; indicators with high resolution; and deeply investigated other segments of the radar equation. Dr. Istvánffy and his team invented or reinvented the optimal installation requirements for "VHF" radars, such as exploration of multipath and quasi-monostatic configurations, the advantages of a horizontally polarized planar phased array, and increased azimuth measurement accuracy applying the fast beam-steering technique, and introduced standards for efficient radar manufacturing for VHF and UHF bands.

The "Sas" long-range radars installed in the Hungarian Platoon considerably contributed to the early warning of the population of Budapest during air attacks, and saved Hungarian citizens beginning on December 20, 1943. This success was possible only because the relatively small Hungarian radar community had professional knowledge in RF technology, and in widely applied and accepted RF standardization processes. It is also important to highlight that the Institute of Military Technology played a crucial rule in radar R&D project management.

The trains of thought and souls of Dr. Jáky and Dr. Bay were so close to each other in the advanced radar-related research that, when Dr, Bay suggested: "we should try to detect and measure microwave, which are reflected from 380,000 km, from the moon," it not only was accepted by Dr. Jáky, but full military support was given to Dr. Bay in April 1944. On February 6, 1946, Dr. Bay's project for a measurement of the Earth-to-moon distance using radar-pulse integration succeeded. This opened a new era for radio astronomy, and gave a proud day for Hungarian science.

Other facts showed that radar manufactured in Hungary was 30% to 40% less expensive, compared to similar types from the German allies. The following comparison based, on the figures from the Hungarian Procurement contracts, shows that the cost of the "Freya" radar was 656 tHUP (thousand HUngarian Pengo), against the "Sas" radar at 150 tHUP; the "Würzburg Riese" at 574 tHUP, against the Bagoly at 250 tHUP; the "Würzburg" at 410 tHUP, against the "Borbála" at 150 tHUP.

At the beginning of the 1950s, Hungarian radar experts again introduced their talent when they developed and manufactured the "LRB-T1" fire-control radar, and proved its superior performance against the SZON-4 radar produced by the former Soviet Union. The political circumstances and the pertaining decision of the destruction of the Hungarian radar activities was not their fault.

The generation of Dr. Bay, Dr. Istvánffy, and Dr. Jáky was very powerful in radar-technology-related expertise. The picture shows that their generation spread all over the world, and had a significant impact on improving western radar systems. Today, everybody knows at least a few of them. Mr. Rudolf (Rudy) Emil Kalman (in Hungarian, Kálmán Rudolf Emil, born in 1930) is a Hungarian-American electrical engineer and mathematical system theorist, best known for his "Kalman Filter." Microwave holography was invented by Mr. Dennis Gabor (1900-1979), a Hungarian-British electrical engineer. His original Hungarian name was Gábor Dénes. Mr. John von Neumann (original name, Neumann János, 1903-1957) was a Hungarian-born American mathematician, who made major contributions to the development of high-speed computers, and was one of the founders of game theory.

11. Acknowledgement

This article consumed a huge amount of work, research, and dedication. Implementation would still not have been possible if we had not had the support of many individuals. We therefore would like to extend our sincere gratitude to all who helped us: especially to Prof. Ing. Gaspare Galati, Tor Vergata University, Roma, Italy, and Prof. Ir. Piet van Genderen, Delft University of Technology, The Netherlands, for support and constructive criticism; and to Gyula Sárhidai, co-Editor of the journal *Haditechnika*, IMT, Hungary, for more than 40 years of collections of material and relevant documents and material analyses support.

12. References

1. I. Balajti and F. Hajdú, "Radar Developments in Hungary During World War II," Microwave and Radar Week, Krakow, May 9-12, 2016, pp. 1-10, ISBN 978-1-5090-2517-6.

2. P. Renner, "The Role of the Hungarian Engineers in the Development of Radar Systems," *Periodica Polytechnica Social and Management Sciences*, **12**, 2, 2004, pp. 277-291.

3. G. Berkovics and Z. Krajnc, "The Beginning of Radars in Hungary," AFASES 2013, The 15th International Conference of Scientific Papers, Brasov, May 23-25, 2013, http://www.afahc.ro/ro/afases/2013/ air_force/ Berkovics_Krajnc.pdf.

4. N. Wassits, *A Magyar Radar 1943-1946*, Békéscsaba, Typografika Kft, 2011, ISBN 978-963-86574-9-9 (The Hungarian Radar) (in Hungarian).

5. P. J. Szabó, *Radarokkal a Lopakodók Ellen*. A magyar katonai légtérellenőrző és radarrendszer története 1917-2014, Budapest, Zrínyi Kiadó, 2014, ISBN: 978 963 327 621 1 (Radars Against Stealth Targets) (in Hungarian).

6. L. I. Farkas, *A Trianoni Diktátum:* eredeti szöveg francia és magyar nyelven, Budapest, 2009, ISBN 978-963-9428-83-6 (The Trianon Treaty) (in Hungarian and French).

7. Z. Barczy and G. Sárhidai, *A Magyar Légvédelmi Tüzérség 1914-1945:* A Boforstól a Doráig, Budapest, Petit Reál, Budapest 2008, ISBN 978 963 9267 39 8 (in Hungarian).

8. Időrosta, L. Kalmar, guest G. Nyári, Echotv, 02. 04. 2016, http://www.echotv.hu/video/111718/20160402_Idorosta, downloaded May 15, 2016 (in Hungarian).

9. "Budincsevics Andor visszaemlékezése", Kézirat. 1972, Haditechnika archívum. (Remembering Dr. Andor Budincsevics, manuscript) (in Hungarian).

10. "A HTI részletes javaslatai rádiólokátor hazai gyártására," Haditechnikai Intézet, 1942, HIM 62969/ eln.-szám., (HTI Detailed Proposals from Domestic Radar Production) (in Hungarian).

11. F. Hajdú, and G. Sárhidai, *A Magyar Királyi Honvéd Haditechnikai Intézettől a HM Technológiai Hivatalig 1920-2005*, (The Royal Hungarian Military Institute of the Ministry of Defense Technology from 1920-2005), Budapest, HM Technológiai Hivatal, 2005. ISBN 963 219 666 X (in Hungarian).

12. E. Kollar, Virtuális Rádiómúzeum. A Hazai Rádiógyártás, (Virtual Radio Museum, the National Radio Production) http://www.radiomuseum.hu/ hradgy_m.html, downloaded May 15, 2016 (in Hungarian).

13. Z. Bay, "Hazai Mikrohullám Kísérletek," *Elektrotechnika*, **38**, 1-5, May 1946, pp. 1-6 ("Microwave Investigations in Hungary During the Second World-War, Part I") ISSN 0367-0708 (in Hungarian).

14. Z. Bay, "Hazai Mikrohullám Kísérletek," *Elektrotechnika*, **38**, 6-8, August 1946, pp. 29-40 (Microwave Investigations in Hungary During the Second World-War, Part II) ISSN 0367-0708 (in Hungarian).

15. E. Istvánffy, "Hazai és Külföldi Radarkészülékek," *Elektrotechnika*, **40**, 1, January 1948, pp. 1-12 ("Home and Foreign Made Radars") ISSN 0367-0708 (in Hungarian).

16. E. Istvánffy, "Radarkészülékek Elméleti és Gyakorlati Problémái," *Elektrotechnika*, **40**, 8, August 1948, pp. 167-184 ("Theoretical and Practical Problems of Radar") ISSN 0367-0708 (in Hungarian).

17. "Kiút többszemközt. Gondok Koszorús Ferenc szobra körül," Echo Tv, 16. 04. 2016. ("The way out of opposite events. Problems around the statue of Ferenc

Koszorús”) (http://www.echotv.hu/video/112036/20160416_Kiut_tobbszemkozt, downloaded May 15, 2016 (in Hungarian).

18. Z. Hantó and N. Szeker (eds.), “Páncélosokkal az Életért – Koszorús Ferenc, a Holokauszt Hőse,” Bp. Kiskapu, 2015, ISBN: 9786158013529 (*Armored with for Life – Koszorús Francis, the Hero of the Holocaust*) (in Hungarian).

19. T. Látos, “Zoltán Bay and the Moon Radar Experiment,” http://www.pulispace.com/en/education/ space-moon-and-the-hungarians/105-zoltan-bay-and-the-moon-radar-experiment, downloaded June 17, 2016.

20. K. A. Norton and A. C. Omberg, “The Maximum Range of Radar Set,” *Proceedings of the IRE*, **35**, 1, January 1947, pp. 4-24.

21. H. D. Griffiths and H. Kuschel, “Passive Radar Systems,” RADARCON 2013 Conference, Ottawa, April 29, 2013.

22. I. BalajtiI, I., G. Kende, and E. Sinner, “Increased Importance of VHF Radars in Ground-Based Air Defense,” *IEEE Aerospace and Electronic Systems Magazine*, **27**, 1, 2012, pp. 4-18.

23. K. Simonyi, “Emlékezés és Töprengés,” *Természet Világa*, **127**, 7, 1996, pp. 299-303, ISSN 0040-3717 (“Remembering and Pondering”) (in Hungarian).

Introducing the Authors

István Balajti was born in Debrecen, Hungary, in 1955. He received his MSc in Electronics, specializing in air-defense radar technology and military tactics studies in Kiev, Ukraine, for six years in 1980. He received his CSc – Candidatus Scientarum for a thesis in radar signal processing from the Hungarian Academy of Sciences, Budapest in 1992. From 1986-2001, he was with Military Technology MoD, Hungary. He has worked for NSPA since 2001. He is a part-time lecturer and (scientific) supervisor of applied military radar technology and science. His main research interests are VHS radar, Gaussian monostatic-twin radar applications, and radar performance “in situ” measurements.

Ferenc Hajdú was born in Budapest in 1965. He graduated from the Military Technical College as a radar engineer. After graduation, he served in the Hungarian air-defense system as a radar company commander for 10 years. He did post-graduate work in Miklós Zrínyi National Defense University in 1999. He has worked in the Military Technical Institute since 2001 as deputy head of the research and development section of MoD. In 2009, he obtained his PhD. His primary field of research is the history of Hungarian military technical research and development. He is a part-time senior lecturer at the National University of Public Service Military Technical Department and the Doctoral School of Military Engineering.

In Memoriam: Yury V. Chugunov

Professor Yury V. Chugunov passed away on Wednesday, August 24, 2016, after a serious illness. He will be greatly missed by his friends and colleagues, both in Russia and around the world.

Yury Chugunov was born on December 5, 1941. He graduated from the Radiophysical Department of Lobachevsky State University of Gorky (now Nizhny Novgorod) in 1964. After that, he became a post-graduate student at that university. He defended his PhD thesis, *The Sources of Electromagnetic Waves in Anisotropic Media*, in 1970. He then worked at the Radiophysical Research Institute in Gorky from 1969 to 1977. Since the establishment of the Institute of Applied Physics of the Russian (Soviet, at that time) Academy of Sciences in 1977, he worked at that institute. He was among the people who largely determined its scientific reputation. Yury defended his doctoral thesis, *Quasi-Stationary Electromagnetic Fields Due to Sources in Plasmas*, in 1988. He became a Professor in 1991, and a Principal Researcher in 1993.

Yury made a pioneering contribution to the theory of antennas in plasmas. His monograph, *Antennas in Plasma*" (1991, in Russian), coauthored with E. A. Mareev, is a classic book on this field. Yury was especially interested in the quasi-electrostatic waves excited by short (as compared to the wavelength in a plasma) dipoles, and propagating along a resonance cone in magnetized plasmas. He found an analytical solution to a problem of the charge distribution along a thin dipole immersed in a magnetoplasma, and calculated its input impedance. He also solved important problems for receiving antennas, such as the calculation of the noise electromotive force induced on a receiver in a nonequilibrium plasma, and the effective length of a quasistatic receiving antenna in a magnetoplasma. He was also interested in nonlinear effects in plasmas that affect the antenna's radiation.

As an outstanding scientist and recognized expert in the field of antennas in plasmas, Yury took part in the design of the spacecraft project Aktivny (Intercosmos-24) and the future project RESONANCE. He was very active in international cooperation. Together with Czech and Canadian colleagues, Yury successfully applied his theoretical results to the interpretation of cluster data on plasma-line emission in the solar wind, and to the analysis of the OEDIPUS-C rocket experiment.

Yury had a very broad scope of scientific interests. He obtained a universal shape for the distribution function of ultra-relativistic electrons due to radiation losses in a strong magnetic field, with applications to pulsar magnetospheres. He developed a theory of curvature radiation in plasmas. He obtained fundamental self-consistent solutions for plasma envelopes around rotating magnetized planets.

In addition to the mentioned monograph, Yury wrote more than a hundred journal articles. His results were highly recognized by the scientific community. He was awarded the Tsiolkovsky Medal of the Russian Federation of Cosmonautics. He was a delegate in URSI Commission H, "Waves in Plasmas," from Russia, and a member of the Russian National Committee of URSI.

For a long time, Yury Chugunov was a Professor at Lobachevsky State University of Nizhny Novgorod. He was advisor to seven PhD students, and numerous masters and bachelors students.

Yury was a many-talented man. He published a book of poems, played guitar and piano, and was keen on sports. Friends, colleagues, and students will remember Yury as a wonderful man, devoted to his family, and committed to science and education. He is survived by his wife, daughter, and granddaughter. His death is a very tragic loss for all of us. We will miss him very much.

Friends and colleagues,
Institute of Applied Physics
of the Russian Academy of Sciences
Lobachevsky State University of Nizhny Novgorod
Space Research Institute of the
Russian Academy of Sciences
E-mail: andrei@appl.sci-nnov.ru

International Union of Radio Science (URSI)

3rd URSI Regional Conference on Radio Science

(3rd URSI-RCRS)

1 - 4 March 2017

TIRUPATI, India

Special Session : "25 years of Indian MST Radar"

FIRST CIRCULAR

As part of the silver jubilee of the establishment of the high power Indian MST Radar, National Atmospheric Research Laboratory (NARL), Dept of Space Govt. of India, Gadanki and the Indian Committee for URSI (INCURSI), (which is under the Indian National Science Academy - INSA) are jointly organising the 3rd URSI-RCRS 2017 during March 1-4, 2017 at Tirupati, India. There will be a special session on the progress in MST Radar based science and technological developments. In addition to the regular sessions, there will be a maximum of five Young Scientist Awards (YSA) and five student paper competition (SPC) prizes. Where appropriate, names of YSA recipients could be recommended for being considered for the YSA awards of the XXXII URSI General Assembly and Scientific Symposium - URSI GASS 2017. Details can be found later on our website.

We welcome participation from researchers in India and abroad to this conference. Participants from neighbouring countries in the Asian and African region with whose science academies INSA has an MOU on scientific cooperation and exchange could avail the facilities under those MOUs.

Interested participants are requested to send an email with "interested" in subject line to ursircrs2017@narl.gov.in.

Important Dates

First Circular:	1 May 2016
Second Circular :	14 August 2016
Abstract Submission deadline:	15 November 2016
Acceptance notification:	30 November 2016
Registration Early bird deadline:	15 January 2017
SPC submission deadline:	10 January 2017
YSA submission deadline:	10 January 2017
Conference dates:	1-4 March 2017

In Memoriam: Richard Smith

Richard Smith (Figure 1), a world expert in ionogram interpretation and teaching ionospheric physics, died on November 9, 2015, after a short illness.

Richard Smith was born on December 1, 1923, in the village of Snape, in Suffolk, where he excelled academically and in sport at school. In 1941, at the age of 17, Richard applied for a junior post as a chemist at the National Physical Laboratory. At his interview, he was told that there were no posts currently available in chemistry, but was asked if he would be interested in working in radio research. He accepted the offer, and joined the Radio Research Station at Ditton Park, near Slough. The Radio Research Station changed its name to the Radio and Space Research Station in 1965, the Appleton Laboratory in 1974, and then the Rutherford Appleton Laboratory in 1979, after a merger of the two organizations. Richard was a key member of staff through these changes, until his retirement in 1983, after 42 years of sterling service.

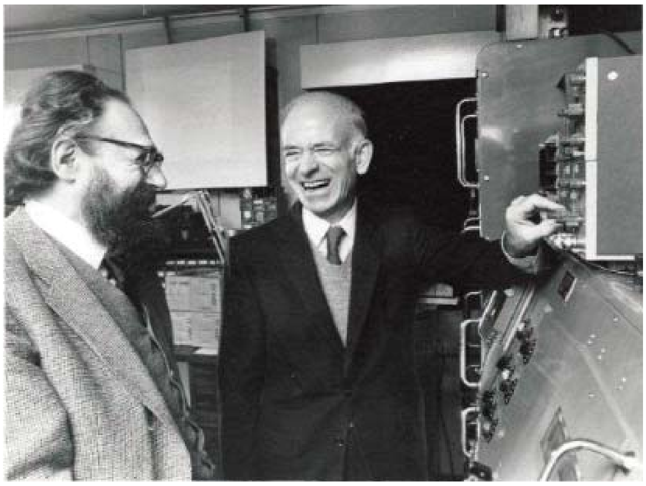


Figure 1. Richard Smith (r), with Kurt Feldmesser, at Appleton Laboratory.

When Richard received his call-up papers for active service in the Second World War, he was fully prepared to comply. However, Sir Edward Appleton, Nobel Laureate for his research on the ionosphere, made a special case for Richard to continue his work. He wrote:

> I am specially interested in the work which is being carried out by Mr. Smith and can state that
>
> a) it is of a secret character,
>
> b) it is required for operational use by all the Fighting Services, and
>
> c) it is also part of a joint inter-allied effort of considerable importance.

Sir Edward also described Richard (still aged only 20) as a man "who, on account of the technical complexity of the problems involved, is virtually irreplaceable." Richard was a member of the team developing radar, the technology that played such a decisive contribution to the outcome of the Second World War.

Following the war, Richard worked on research into the ionosphere at Slough. He began his long association with Dr. W. Roy Piggott, often regarded as one of the founding fathers of ionospheric physics. In addition to a full-time job, Richard studied for a degree in evening classes, graduating with a BSc in Physics.

In 1951, Richard became the officer in charge of ionospheric soundings in Singapore, which involved operating one of the original Union Radio ionosondes. Some of the design features included three bicycle chains to keep the transmitter and receiver synchronized, and to change the operational frequency ranges. He also carried out the analysis of the ionograms.

On his return to the UK in 1954, Richard worked on the development of transistors and the operation of a satellite tracking facility. He became the computer operations manager.

In the early 1970s, Richard took charge of the organization and operation of the World Data Centre C1 for the Ionosphere and Rockets and Satellites. He was responsible for overseeing the interpretation of ionograms from Slough. He was also called upon to give short courses to young scientists and engineers working with British Antarctic Survey, to enable them to collect and analyze ionospheric data whilst stationed in the Antarctic. Richard's deep understanding of the ionosphere and ionogram interpretation, combined with his meticulous approach, meant that the quality of the ionospheric data sets from Antarctica was outstanding. As a result, much novel science research was carried out with the data, some of which was undertaken by the young Antarctic scientists who were inspired by Richard to follow careers in ionospheric research.

One of the great successes of the International Geophysical year, 1957-58, was the careful and systematic study of the ionosphere by many workers around the world who used agreed-upon standardized methods for the analysis of ionograms. These rules for ionogram interpretation were established in early 1950, and updated in 1972. However, the key parts of ionogram interpretation were not consistent with current practices. The first four chapters were therefore later revised, and resulted in the publication of the *URSI Handbook of Ionogram and Reduction*, Report UAG23A. Richard played an absolutely key role in revising these chapters, and several of his teaching aids were incorporated into the new guidelines.

In 1977, Richard was awarded the Queen's Silver Jubilee Medal for his outstanding service to the Appleton Laboratory. On his retirement in 1983, Richard was thanked by the Chair of the Science and Engineering Research Council for his "outstanding contribution," and told that "the high international standing of the World Data Centre...results largely from your conscientious and dedicated efforts."

Richard's contributions to ionospheric research did not stop on retirement. He was heavily involved in several research studies comparing ionograms scaled by humans with those scaled by computer. Richard's depth of knowledge of the ionosphere from many parts of the world significantly contributed towards producing more-consistent data sets between manual- and automatically scaled data. Some of his knowledge is now enshrined in the analysis software used today

In his spare time, Richard enjoyed daily walks, bird-watching, gardening, playing tennis, and listening to music. Richard was married to Robin for 56 years, and is survived by his daughters Vicky and Edwina, and grandchildren Edward and Jenny.

Through his entire life, Richard was one of the unsung heroes of ionospheric research, running ionosondes, analyzing the data, developing the World Data Centre for the Ionosphere, internationally sharing his immense knowledge, and training many generations of ionospheric technicians and researchers. We shall greatly miss this quiet gentle man, who gave so much to others.

Alan Rodger
Formerly British Antarctic Survey
E-mail: alanrodger42@gmail.com

Book Reviews

George Trichopoulos
Electrical, Computer & Energy Engineering ISTB4 555D
Arizona State University
781 E Terrace Road, Tempe, AZ, 85287 USA
Tel: +1 614 364 2090
E-mail: gtrichop@asu.edu

Very Low Frequency Space Radio Research at Stanford 1950-1990: Discovery, Innovation, and Analysis, Supported by Field Work Extending from Antarctica to Alaska by Donald L. Carpenter, PEFC/16-33-415, *DID1334763*, December 22, 2015, Lulu Press [Editor's note: The Lulu Press version of this book was used for this review. However, as this issue of the *Radio Science Bulletin* went to press, the book did appear to be available from this publisher. A slightly earlier version, under the title *The Early History of Very Low Frequency (VLF) Space Radio Research at Stanford: Discovery, Innovation, and Analysis, Supported by Field Work Extending from Antarctica to Alaska*, dated July 30, 2014, is available for downloading at http://vlf.stanford.edu/research_ext/history-very-low-frequency-vlf-radio-research-stanford]

This book is a historical review, focused on the study of whistler waves propagating in the Earth's ionosphere and magnetosphere. In an unconventional style, it recalls the work done between 1950 and 1990 by members of the VLF group, which was created in 1955 by Prof. Robert A. Helliwell at the University of Stanford, California. The author joined this group in 1952, and retired in 1991 as Emeritus Professor (Research). During this long career, he was remarkably active, both individually and in collaboration with colleagues from the US and from some foreign institutions on projects in his field of expertise: "magnetospheric VLF wave analysis and interpretation."

This book contains five parts: (1) "Ground Observations," (2) "Space Observations," (3) "Field Operations," (4) "Wave-Induced Particle Precipitation," and (5) "Studies of Wave-Particle Interactions in Space." Each of these parts is formed of subsections briefly chronologically recalling remarkable events or advances made by members of the Stanford VLF group, and by collaborators of Dr. Carpenter, throughout his exceptionally fruitful career. This book is a historical account of his life work. It is sometimes accompanied with humorous anecdotes, such as that of "*the search of a lost rocket booster in the snow field near Siple, Antartica*," by Don Carpenter, a dedicated jogger and experienced runner (Section 3.7).

Many personal photographs of Don and of his colleagues nicely illustrate the 215 pages of this special volume. A significant number of whistler spectrograms of historical interest are also included. They illustrate important discoveries by the author. One example is his famous observation in 1963 of "knee whistlers," which led him to discover a fully unexpected feature of the Earth's magnetosphere. This feature was first called the "Carpenter's knee," and it is now known as the "plasmapause."

The ways in which the plasmapause surface varies with local time, with geomagnetic activity, and with season are other major scientific contributions by the author. Many interesting and important diagrams, plots, or photographs are shown in this "album of souvenirs," recalling the scientific contributions made by Carpenter and his colleagues at Stanford.

The author is well known for his intuitive interpretation of data and measurements. There are only a few basic mathematical equations in his book. It is therefore not the place where readers will find argumentative theories, nor detailed discussions of controversial issues or alternative physical interpretations. For sure, experimentalists and data analysts will find in this book relevant stories that greatly marked the paradigms in use in magnetospheric physics since 1950.

The history recounted in this book sheds unprecedented light on some of the scientific advances made between 1950 and 1990 in magnetospheric VLF whistler-wave measurements and their interpretation. It reports these advances in a courteous style, which was appreciated by this reviewer. This is what makes this book an unconventional and attractive historical publication. It is more intuitive and informal than some other historical reviews, e.g., that contributed by Dr. Carpenter for the book, *The Earth's Plasmasphere*, published by Cambridge University Press in 1998.

The "Foreword" to Carpenter's book was written by L. R. O. Storey. Storey was a pioneer who in 1953 identified the properties of the paths of VLF whistler waves propagating along geomagnetic field lines. This was a key discovery upon which subsequent developments reported by D. L. Carpenter have been grounded.

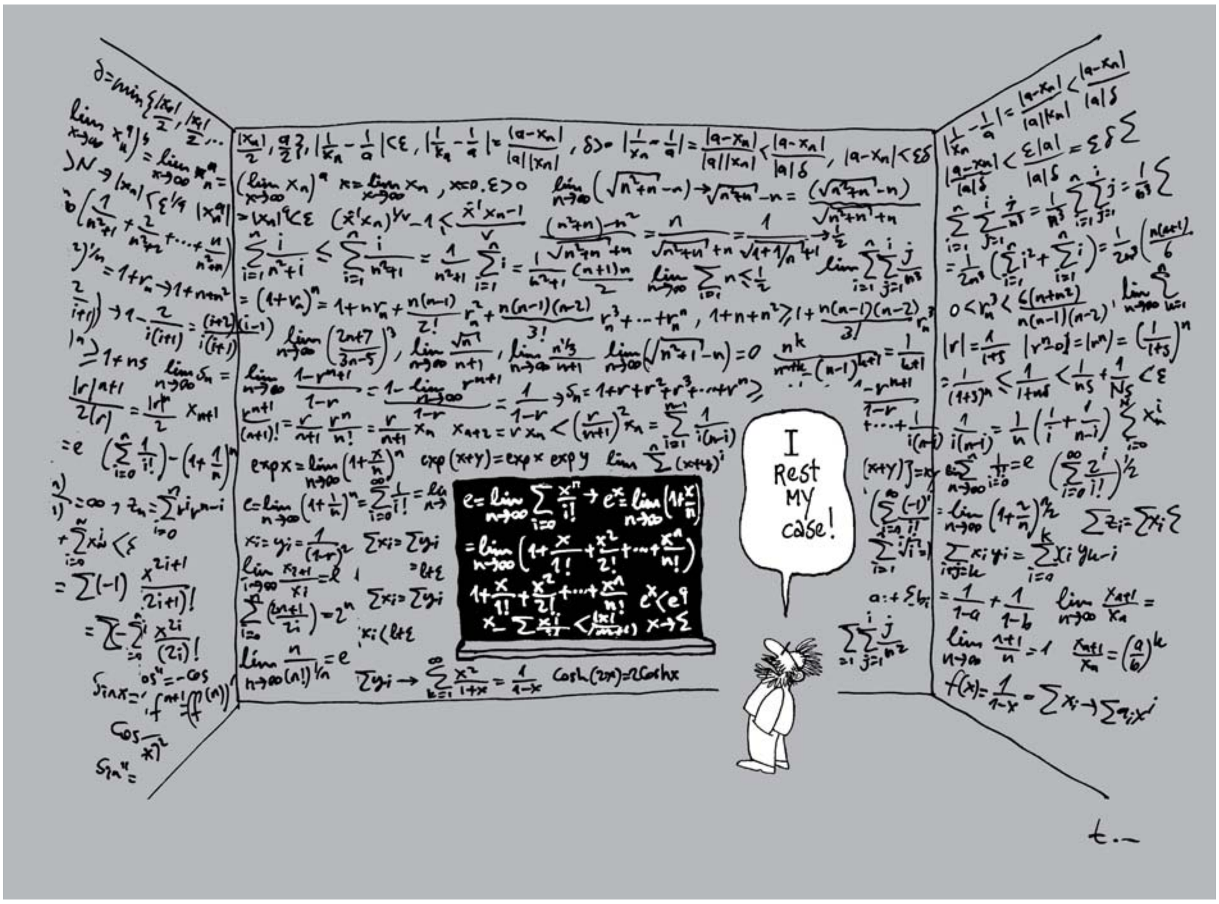
Senior experimenters who have been involved in ground-based or satellite ULF and VLF whistler or chorus observations will enjoy reading this "album of souvenirs." Indeed, they will be reminded of early achievements in this important field of space physics. They will also learn about not-so-well-known issues related to the "knee effect." One such historical event was that which took place at the XIVth URSI General Assembly in Tokyo, in 1963, when Don Carpenter and Konstantin Gringauz met each other for the first time. Indeed, K. I. Gringauz had detected a sharp drop in the protonospheric density distribution with ion-trap instrumentation flown on the Russian SPUTNIKs and LUNA-2, a few years before the "Carpenter's knee" was revealed from Stanford's ground-based whistler observations.

Lecturers in space physics as well as their students can glean unconventional knowledge about the physics of magnetospheric VLF waves and wave-particle interactions that they may not find elsewhere, in this interesting book. What Dr. Carpenter did not include are the physical mechanisms responsible for the formation the *plasmasphere boundary layer* and the *plasmaspheric wind*, which are making headway. However, this might possibly be incorporated in a future issue of this print-on-command book. The book is produced by Lulu Press, an independent publisher offering a breakthrough in reading technology: the solar-powered book!

J. F. Lemaire (Emeritus Prof.)
UCL, Louvain-La-Neuve & BIRA-IASB, Brussels
E-mail: lemaire@astr.ucl.ac.be

Et Cetera

Tayfun Akgül
Istanbul Technical University
Dept. of Electronics and Communications Engineering
Telecommunications Division
80626 Maslak Istanbul, Turkey
Tel: +90 212 285 3605; Fax: +90 212 285 3565
E-mail: tayfun.akgul@ieee.org



2017 IEEE International Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting

San Diego, CA

July 9th-15th, 2017

The 2017 IEEE AP-S Symposium on Antennas and Propagation and USNC-URSI Radio Science Meeting will be held on July 9-15, 2017, at the Manchester Grand Hyatt hotel in San Diego, CA. The symposium and meeting are cosponsored by the IEEE Antennas and Propagation Society (AP-S) and the US National Committee (USNC) of the International Union of Radio Science (URSI). The technical sessions, workshops, and short courses will be coordinated between the two organizations to provide a comprehensive and well-balanced program. This meeting is intended to provide an international forum for the exchange of information on state-of-the-art research in antennas, propagation, electromagnetic engineering, and radio science. The paper-submission deadline is **January 16, 2017**.

Steering Committee

General Chair
Dan Sievenpiper *dsievenpiper@eng.ucsd.edu*
Vice Chair
Gabriel Rebeiz *grebeiz@eng.ucsd.edu*
Technical Program Chairs
Vitaliy Lomakin *vlomakin@eng.ucsd.edu*
Filippo Capolino *f.capolino@uci.edu*
URSI/AP Liaison
Ross Stone *r.stone@ieee.org*
Special Sessions Chair
Kathleen Melde *melde@email.arizona.edu*
Student Paper Competition Chairs
Boubacar Kante *bkante@eng.ucsd.edu*
Mona Jarrahi *mjarrahi@ucla.edu*
Student Design Contest Chairs
John Rockway *john.rockway@navy.mil*
Jay Rockway *jay.rockway@navy.mil*
Short Courses and Workshops
Ethan Wang *ywang@ee.ucla.edu*
Satish Sharma *ssharma@mail.sdsu.edu*

Local Arrangements
Susan Stone *SueLStone@hotmail.com*
Joy Rockway *rockway4@gmail.com*
Publicity Chair
Jamesina Simpson *jamesina.simpson@utah.edu*
Finance Chair
Carson White *crwhite@HRL.com*
Exhibits
Kevin Geary *kgeary@HRL.com*
Jim Schaffner *jhSchaffner@HRL.com*
Sponsors
Mahta Moghaddan *mahta@usc.edu*
Social Programs and Hospitality
Susan Stone *SueLStone@hotmail.com*
Joy Rockway *rockway4@gmail.com*
Jane Schaffner *janeschaffner27@gmail.com*
Women in Engineering
Jeanne Quimby *jeanne.quimby@navy.mil*

www.2017apsursi.org

Paper Submission

Authors are invited to submit contributions for review and possible presentation at the symposium or meeting (the "conference") on topics of interest to AP-S and USNC-URSI, including advancements and innovations in the fields of electromagnetics, antennas, and wave propagation. Suggested topics and general information are listed on the Web site. In addition to regularly scheduled sessions for oral and poster presentations, there will be a student paper competition, as well as special sessions, workshops, and short courses that will address timely topics and state-of-the-art advancements in these fields. AP-S submissions must be in standard IEEE two-column format, and must be two pages in length. USNC-URSI submissions may be in either a one-page, one-column format with a minimum length of 250 words, or in the IEEE two-page, two-column format with a length of two pages. In all cases, only accepted and presented submissions that are in the IEEE two-page two-column format and substantially fill the two pages will be submitted for possible inclusion in IEEE Xplore, if the author chooses submission to Xplore. All accepted and presented submissions will appear in the proceedings distributed at the conference. The presenting author will be required to register for the conference by April 7, 2017, in order for their paper to be included in the conference. A complete list of AP-S and URSI topics, as well as detailed instructions including formats and templates, are available on the conference Web site: **www.2017apsursi.org**

AP-S Student Paper Competition

Eligible entries in the Student Paper Competition must have only one student author, and that student must be the first author. Each additional coauthor must submit a signed letter indicating that his/her contribution is primarily advisory. Letters must be in PDF format and must be uploaded to the symposium's student paper Web site in the indicated area at the time the paper is submitted. All Student Paper Competition entries will be evaluated using a double-blind review process, in addition to the normal review process used for regular submissions. Detailed instructions are available on the conference Web site. For additional information, contact Mona Jarahi (mjarrahi@ucla.edu).

Special Sessions

Requests to organize special sessions should be submitted to Kathleen Melde (melde@email.arizona.edu) no later than **October 9, 2016**. Each proposal should include the title of the special session, a brief description of the topic, an indication of whether the proposed session is for AP-S, USNC-URSI, or is joint, and justification for its designation as a special session. All proposals should be submitted in PDF format. Special sessions will be selected and finalized by the end of November 2016. At that time, additional instructions will be provided to the organizers of the special sessions chosen for inclusion in the conference. The associated papers or abstracts will be due **January 16, 2017**. A list of special sessions will be posted at the symposium Web site in December 2016.

Exhibits

Industrial, academic, and book exhibits will be open June 11-13, 2016. Exhibitor registration and additional information can be found on the conference Web site.

Short Courses/Workshops/Tutorials

Several short courses and tutorials on topics of special and current interest will be solicited by the technical program committee and organized for the conference. Individuals who wish to organize a short course or workshop should contact Ethan Wang (ywang@ee.ucla.edu) or Satish Sharma (ssharma@mail.sdsu.edu) by **November 14, 2016**.

Randy L. Haupt
Colorado School of Mines
Brown Building 249
1510 Illinois Street, Golden, CO 80401 USA
Tel: +1 (303) 273 3721
E-mail: rhaupt@mines.edu

Kevlar

Randy L. Haupt and Amy J. Shockley

I like to ride my bike, and if I can avoid driving a car, I do. After moving to Colorado almost six years ago, I found that I was getting a flat tire on my bike about once a month. I hate changing inner tubes, especially on the road. My solution: Kevlar. I bought Kevlar tires for my bike. I wanted to guarantee that I do not get flat tires. After all, Kevlar is used in bulletproof vests, so no little thorn or sharp object will interrupt my bike ride anymore. Well, a little while ago, I came home with a flat tire! How can that be? I found a small thorn that penetrated the Kevlar and put a tiny hole in my tube that caused a slow leak. My tire can stop a bullet, but not a tiny thorn? I guess Superman can stop a speeding train, but crumbles in the vicinity of kryptonite.

My solution: get thorn-proof tubes for my Kevlar tires. Now, I ride around with Kevlar tires and thorn-proof tubes. I have not gotten any more flats, but I have significantly slowed down. The tires and tubes are very heavy, and the rolling resistance of the tires is high. I rationalize that I am getting more exercise per mile than all the people zipping by me – plus, they wear Spandex, and I wear a long-sleeve shirt and short pants.

Terrorists are thorns in our lives. Airport security discourages them from boarding airplanes, but travelers pay the price, with long security lines and the high cost of bottled water in airport terminals. Keeping us safe requires governments adapting to the latest terrorist approach; however, it seems like the terrorists always find new tactics that avoid the latest protections. There are an infinite number of ways that one person can terrorize another. Complete protection is impossible. Governments and airports continue to implement new efforts, much like my addition of thorn-proof tubes, and each new protective measure slows down travelers.

Recently, some old friends had a high-school-aged son who committed suicide. He was extremely bright, athletic, and musically talented. I drove a couple of hours to attend the funeral service, and learned that he was the third student at that high school in a two-week period to commit suicide. The parents thought they had their son covered in Kevlar: they did everything right. They were a model family. I know them, and they are wonderful. Somehow, that suicide thorn penetrated their Kevlar. Devastating.

My wife loves buying clothes for our two granddaughters. When I am with her on a shopping trip, I occasionally make suggestions. Sometimes, those suggestions are deemed appropriate. I think that next time, I am going to suggest that she buy them little dresses and shirts made from Kevlar. Those little girls are too precious to lose to some thorn in life. The difficult tradeoff is finding the balance between protection and freedom. Overbearing parents (or in this case, grandparents) can also have negative effects. The complexity of every situation, and the varying responses from different people, means that there is no easy answer on how to best obtain this balance. It is a scale that we have to constantly monitor, adapt, and adjust to prevent tipping too far in one direction or the other as circumstances change (i.e., the addition of my new tubes, increased TSA regulations, and responding to children as they grow and become embedded in cultures that are out of your control).

We all try to protect the most valuable thing in our lives, but often there are tradeoffs. I am no longer a speed demon on my bike, but I don't get flats. Some people will not fly on airplanes, and those that do face the security hassles that are deemed necessary to protect against terrorist attacks. Some people home-school their children, which may protect them from undesirable influences, but limits the child's exposure to some good things, as well. Balancing protection and freedom is one of the ethical dilemmas in life. Considering the tradeoffs before overreacting to or ignoring a threat leads to better decisions and a better society.

Please note that the URSI Secretariat
has moved to a new address
since15 March 2016:

URSI Secretariat
Ghent University - INTEC
Technologiepark-Zwijnaarde 15
B-9052 Gent
BELGIUM

The telephone and fax number remain the same :
Tel. : +32 9-264 3320
Fax: +32 9-264 4288

James C. Lin
University of Illinois at Chicago
851 South Morgan Street, M/C 154
Chicago, IL 60607-7053 USA
E-mail: lin@uic.edu

Potential Game Changer for Mobile-Phone Radio-Frequency Radiation Carcinogenesis

Readers of the *Radio Science Bulletin* may recall my recent article from a couple of issues back, in March, 2016 [1], in which I mentioned an unclassified five-year project: a US government-led health-effects research study of two-year (or lifelong, in most cases) exposure of rats and mice to radio-frequency (RF) radiation used for wireless cellular mobile-telephone operations. This project, which began in 2005, is the largest animal cancer study ever undertaken by the National Toxicology Program (NTP) of the National Institute of Environmental Health Sciences (NIEHS), with a budget of $12 million, at the time.

Although years overdue – the project has been ongoing for more than 10 years, with huge budget overruns, and an estimated price tag of $25 million or more of US taxpayers' money – it appears to need still more time to complete data analysis and evaluation. The NIEHS/NTP had been rather reluctant to release any reports. In contrast to the scientific norm, project personnel have not discussed any results or made any presentations of their findings at scientific meetings.

Surprise! On May 26, the US government project reported occurrences of two types of rare cancers in RF-exposed rats: malignant gliomas in the brain, and schwannomas of the heart [2]. These results represented partial findings from the project. They purportedly were reviewed by expert peer reviewers, selected by NTP and National Institutes of Health (NIH).

At an hour-long teleconference held by Linda Birnbaum, the Director of the NIEHS and NTP, and John Bucher, the leader of the study and Associate Director of NTP, a summary of the report was presented on May 27. Michael Wyde from NTP, who ran the study, also made a presentation during a "Hot Topics" session on Wednesday, June 11, at the BioEM 2016 meeting of the Bioelectromagnetics Society and European Bioelectromagnetics Association, which took place in Ghent, Belgium.

It is interesting to note that the singular and largest animal cancer study ever undertaken by NTP – the cell-phone RF exposure of rats and mice project – was sole-sourced through a contract to an industrial research firm [3]. Furthermore, reporting occurrences of two types of cancers in RF-exposed rats (malignant gliomas in the brain and schwannomas of the heart) by NTP may have been somewhat of a challenge, or perhaps a present dilemma. To wit, John Bucher, the Associate Director overseeing the NTP study, shared in January 2010 with North Carolina's leading newspapers (the *Charlotte Observer* and the *Raleigh News & Observer*) that he "doubts scientific research can demonstrate a link between cell phones and cancer." Bucher was quoted as saying, "I anticipate either no correlation or, if anything is seen at all, it won't be a strong signal" [3]. NIEHS and NTP are physically located in Durham, North Carolina.

Equivocal and inconsistent, published animal cancer studies on RF exposures have been controversial [4]. They have posed uncertainty to assessments of health risks from RF exposure. Nevertheless, in 2011 the World Health Organization's International Agency for Research on Cancer (IARC) classified exposure to RF electromagnetic fields, including those used for cell phones, as possibly carcinogenic to humans [5].

The IARC had assessed available scientific papers. It concluded that while evidence was incomplete and limited, especially with regard to results from animal experiments, published epidemiological studies reporting increased risks for gliomas (a type of malignant brain cancer) and acoustic neuromas (a non-malignant tumor of Schwann-cells sheathed auditory nerves) among heavy or long-term users of cell phones were sufficiently strong to support a 2B classification of possibly cancer-causing in humans for exposure to RF electromagnetic fields.

The NIEHS/NTP's announcement of animal results from their large RF health-effect study is a major event. Aside from contributing to current scientific knowledge on a very important public-health issue, NTP's richly deserved reputation for identification of chemical and other environmental carcinogens would add more credence to the patchy animal data on exposure to mobile-phone RF radiation. Given NTP's observation of two types of cancers in RF-exposed rats (malignant gliomas in the brain and schwannomas of the heart) in laboratory rats, it is conceivable that IARC could upgrade its epidemiology-based classification of RF exposure to the next higher level, 2A: probably carcinogenic to humans.

That said, it should be noted that the NTP cell-phone RF-exposure experiment was far from being perfect. It had its flaws and limitations, even though it was large, rather expensive, and took a long time to get to this point. There may even be better ways to do it. However, it served to recognize that few things are known with the degree of certainty that many may take for granted, and some would assume or rather prefer.

Take the renowned Newton's law of gravity. An apple falling from a tree to the ground may have inspired Newton to formulate the classic theory of gravitational force. The fact is that apples may not always fall on the same exact spot on the ground each time an apple falls. That spot is influenced by many ambient environmental conditions. Determination of the precise location an apple could fall is replete with uncertainties. The spot on the ground where an apple falls would be subject to wind direction and speed, temperature, humidity, particulate matter in the air, and even the time of day, among other factors.

This happens in physical science where problems have been mostly deemed as deterministic. Exactness is still a matter of probability and statistics. Ponder the case of biology, where variability is notorious and vagaries are facts of life.

Now, back to issue at hand: the NTP study. The announced study included partial findings of occurrences of two rare tumor types in male Harlan Sprague Dawley rats, exposed to mobile-phone RF radiation. What is interesting to note is that while acoustic neuromas in human brains and schwannomas in rat hearts were independently observed from two different mammalian body sites, there nevertheless could be a connection. Schwann cells wrap around both nerve tissues in the heart and along the auditory pathways. Gliomas were reported both in human and rat brains from mobile-phone RF exposure research.

The NTP studies involved lifelong (two-year) RF exposures of the entire bodies of rats and mice, using multimode reverberation chambers equipped with shims and mode stirrers to help enhance more-uniform RF field distributions inside the chamber. For rats, 900 MHz RF radiation was used as the exposure source. However, beyond the "GSM or CDMA modulation and frequency that are primarily used in U.S. wireless networks," no other specific technical details were provided.

Whole-body-average RF absorption rates (SAR) of 0 W/kg, 1.5 W/kg, 3 W/kg, or 6 W/kg were investigated. The field strengths used for RF exposure were often adjusted to accommodate age-related changes in body mass to maintain desired SAR levels. These SARs did not raise the body temperatures of exposed animals by more than 1°C. It is noted that 1.6 W/kg and 2.0 W/kg are limiting values established by the Federal Communications Commission (FCC) in Washington, DC, and the International Commission on Nonionizing Radiation Protection (ICNIRP) in Munich, Germany, respectively.

Exposures to RF were initiated *in utero*, beginning with the exposure of pregnant dams and continuing throughout gestation. After birth, dams and pups were exposed in the same cage through weaning, at which point the dams were removed, and exposure of 90 pups per sex per group was continued for up to 106 weeks.

A cumulative daily RF exposure duration of about 9 hr/day was conducted 7 days/week over a period of approximately 18 hr for 10 min on and 10 min off of mobile-phone RF radiation.

A single, unexposed (0 W/kg) group of each sex served as common, experimental controls for both GSM and CDMA modulations. These control rats were housed in identical reverberation chambers, except for RF exposure. The environmental conditions of each chamber was similarly regulated, and was maintained on a 12-hr light/dark cycle throughout the studies.

The specific findings from the rat studies were occurrences of two rare tumor types in male Harlan Sprague Dawley rats exposed to cell-phone RF radiation, malignant gliomas in the brain, and schwannomas of the heart.

For malignant gliomas, the NTP authors indicated a statistically significant positive SAR-dependent trend in the incidence ($p < 0.05$) for CDMA-modulated RF radiation. There was not a statistically significant difference between exposed male rats compared to control males for any of the RF groups. While a low incidence (2%) of malignant gliomas was observed in exposed male rats, no malignant gliomas were observed in controls. However, the historical control incidence in NTP studies was also 2.0% (range: 0% to 8%).

Moreover, in RF-exposed female rats, malignant gliomas were observed in three rats (0.55%); none were found in any of the control females. The historical control incidence at NTP in this case was 0.18% (range: 0% to 2%).

Of particular note were schwannomas of the heart. Schwann cells proliferate throughout the body, not only in the heart. They often appear like a sheath wrapped around associated nerve tissues. The number and incidence of schwannomas observed in tissue sites other than the heart of GSM- and CDMA-RF-exposed males (11 and 2%) were not significantly different from control rats (3 and 3.3%). NTP's historical control incidence of schwannomas for these rats was 1.3% (range: 0% to 6%).

Schwannomas of the heart were observed in male rats in all exposure groups for both GSM- and CDMA-modulated RF radiation (4%), while none were observed in controls. For both modulations, there was a significant SAR-dependent trend in the incidence of schwannomas of the heart ($p < 0.05$). Moreover, the incidence of schwannomas in the 6 W/kg male rats was significantly higher in CDMA-modulated RF-exposed male rats compared to controls.

In female Harlan Sprague Dawley rats, there was no statistically significant or RF-exposure-related effect on the incidence of schwannomas in the heart, or in the combined incidence in the heart and other tissue sites.

The Schwann cell response to GSM- and CDMA-modulated RF exposure appears to be specific to the heart tissue of male rats.

References

1. J. C. Lin, "Public Exposure to Radio Frequency, Microwave and Millimeter-Wave Electromagnetic Radiation," *URSI Radio Science Bulletin*, No. 356, March 2016, pp. 49-51.

2. M. Wyde, M. Cesta, C. Blystone, S. Elmore, P. Foster, M. Hooth, G. Kissling, D. Malarkey, R. Sills, M. Stout, N. Walker, K. Witt, M. Wolfe, and J. Bucher, "Report of Partial findings from the National Toxicology Program Carcinogenesis Studies of Cell Phone Radiofrequency Radiation in Hsd: Sprague Dawley rats (Whole Body Exposure)," *bioRxiv*, http://dx.doi.org/10.1101/055699, first posted online May 26, 2016.

3. J. C. Lin, "The Unusual Story of the IARC Working Group on Radio Frequency Electromagnetic Fields and Mobile Phones." *URSI Radio Science Bulletin*, No. 338, September 2011, pp. 54-55; J. C. Lin, "Reply to Letter to the Editor Regarding a Column by Dr. J. C. Lin," *URSI Radio Science Bulletin*, No. 339, December 2011, p. 6.

4. J. C. Lin, "Carcinogenic Effect of Wireless Communication Radiation in Rodents," in J. C. Lin (ed.), *Advances in Electromagnetic Fields in Living Systems, Volume 5*, New York, Springer, 2009, pp. 35-82.

5. R. Baan et al. (on behalf of the WHO International Agency for Research on Cancer Monograph Working Group), "Carcinogenicity of Radiofrequency Electromagnetic Fields," *The Lancet Oncology*, **12**, 7, 2011, pp. 624-626.

Asta Pellinen-Wannberg
Umeå University, Department of Physics and
Swedish Institute of Space Physics
S-90187 Umeå, Sweden
Tel: +46 90 786 7492
E-mail: asta.pellinen-wannberg@umu.se

Introduction from the Associate Editor

This time, I present Galina Ryabova, DSci and Professor of Physics from the Tomsk State University Physics Faculty. Tomsk is located in the middle of Russia, as far from the Pacific Ocean as from the Atlantic Ocean.

I met Galina for the first time at the Meteoroids2001 conference, which we organized in Kiruna, Sweden, in 2001. At that time, we were euphorically happy to finally be able to invite our Russian colleagues to visit and discuss both science and everything else with us. We sent one of our local Russians on a bus to welcome and pick up the group of around 20 scientists from the railway station in Rovaniemi, Finland. When after a long tour our guests stepped off the bus in Kiruna, one could at once recognize Galina. She was confident, had cool red hair, an energetic handshake, and she spoke very good English. She later told me that her mother had been a headmaster at the local school in her hometown, Norilsk, in Northern Siberia. She had decided that all the kids should learn English from their early years. It is always wonderful to meet Galina. She has had a great scientific career, extending from east to west, which she describes with her own words, below.

Reflections on a Career in Radio Science

Galina O. Ryabova

Research Institute of
Applied Mathematics and Mechanics
Tomsk State University
Lenin pr. 36, build. 27, 634050 Tomsk
Russian Federation
Tel. +7 (3822) 529776
E-mail: goryabova@gmail.com

My way in science in general, and radio science in particular, began in my third year in the Tomsk State University, about 40 years ago. As with most of the students (and I observe this phenomena every year), I had a rather foggy idea about real science. It so happened that our lecturer was Remir Lazarev, who participated in meteor radar observations in Tomsk in the 1960s. He became my first supervisor. My first “scientific” work was the calculation of the mass-distribution index of meteors, using a pencil, a ruler, and cross-sectional paper. It was the first point in my scientific career, which indeed can be approximated by a straight line.

My graduate work dealt with calculation of the incident flux density of meteor showers by the Bel’kovich-Kaiser method. I spent one month in Kazan, at Engelgardt Astronomical Observatory (AOE), where Oleg Bel’kovich headed the meteor department. There, I got the first lessons of real science and work in a research team. I’ll give just one example to explain. At that time (1971), we had no personal computers, and the only computer of the AOE was very busy, so computer time for a student might be scheduled only at night. Can you imagine my astonishment when one by one, the entire department appeared in the computer room to discuss my results: dear me – the "results" of a fifth-year student!

After graduating from Tomsk State University, I took the position of a junior researcher in the Department of Astrometry and Celestial Mechanics, and I am still there. Our small meteor group (four persons) worked at calculating the incident flux density for radar meteors. At that time, the Tomsk meteor radar had already ceased to exist, and we worked in collaboration with observers from Dushanbe (Tadjikistan) and Kazan. Within five years, we managed to develop two methods for flux calculation.

I was the youngest member of our team, and naturally, the topic I worked on was not my own choice. After five years, I felt that I had matured enough for independent research. I tried this and that, but was not satisfied. Once Oleg Bel'kovich gave me a preprint of the paper by Fox, Williams, and Hughes (1983) about the rate profile of the Geminid meteor shower. I was interested, and later absorbed, by this article. I tried to repeat this work, and an idea came to me. This resulted in a peculiar method and the next 20 years of modeling.

Well, I found my topic, and I asked Oleg Bel'kovich, the head of AOE and the President of IAU Commission 22, "Meteors, Meteorites & Interplanetary Dust," at that time, to be my supervisor. Let me remind you that I lived and worked in Tomsk, and Oleg was in Kazan (about 40 hours by train), and we had no e-mail. I visited my supervisor a couple of times in a year, so my aspiration for independence was satisfied. I had to solve minor and major problems myself, and that certainly slowed down my work, but gave me a very strong foundation.

My scientific youth fell on time, when every year we had at least one large meteor conference in the Soviet Union, and a couple of smaller meetings. It was quite usual for us to leave for a seminar in Moscow, or for a library in Leningrad. These were very effective developing factors, as I now understand.

In 1990, I defended my PhD dissertation, in the last moment before "perestrojka." We later just tried to survive and do what we could to save our science. Sometimes, we had no salary for three to four months, but continued our research. We lost many young scientists, but managed to maintain the core of our department. I got my DSci in 2002. I did research into meteoroid streams of various origins, and into the precession and nutation of the asteroid Geographos as a side problem. Until then I managed to avoid teaching, but after I got the DSci, that became unavoidable. Science funding had been reducing like *La Peau de chagrin*, and the only occupation that was not clashing with science was teaching. Nothing has changed until now in this relationship.

Perhaps you know, perhaps not, but in the Soviet Union, travel abroad was not easy. The first time I tried to participate in a conference abroad, namely, "Asteroids, Comets, Meteors III," in Uppsala, Sweden, was in 1989. I was on the waiting list, but at the last moment, the decision was made in favor of my elder colleague (a good researcher, but who did not speak English). My first conference abroad was thus Meteoroids 2001 in Kiruna, organized by Asta Pellinen-Wannberg, with colleagues.

Since then, I have grabbed every opportunity. I mostly use my own savings, and that sometimes surprises my European colleagues. Why do I do that? The answer is simple. The last meteor conference in Russia was in 1999. If 30 years ago we had about one hundred meteor astronomers, we now have about ten, but researchers, not hundreds. The scientific community and personal contacts are the "ground" for researchers. What happens to a plant without the ground? That is why I am *very* grateful to organizing committees for supporting me.

I abandoned radio science many years ago, but it did not abandon me, as it turned out. At the International Meteor Conference 2004 in Bulgaria, we had a very serious talk about knowledge, which can be lost. The result was the Radar Meteor School 2005 in Oostmalle, Belgium, where Oleg Belkovich explained the details of his method of meteor-flux calculations during a week. His lectures were written down by participants and published in English. This school and the following RMS2006 (the Netherlands) and 2007 (France) had no other effects besides publications, and probably some inspiration for their participants. The progress was small, but it was progress, and there may be a continuation.

Now some words about women in science. I was lucky, because from the very beginning I got into a "greenhouse," never suffered from any gender discrimination, and always had support and understanding in any difficult life situation. This happened because for about 40 years I have been working in a department headed by a female. This is Prof. Tatyana Bordovitsyna. Gender inequality does not exist in our department. Definitely, it is not so in the wide world. Several years ago, I attended a meeting of our local Professor's Society. There was an award ceremony, and it amazed me that only 20% of the winners were females. At home, I looked at a reference book, *Professors of Tomsk State University*, and calculated. All was correct: the percentage of female professors was exactly 20%. Does this mean that women are not interested in science? I do not think so. that is why I do support URSI's quota approach, mentioned by Asta (*Radio Science Bulletin*, No. 354, September 2015, p. 44).

Introducing the Author

Figure 1. A picture of Galina Ryabova.

Galina Ryabova is a Professor of Physics at the Tomsk State University. She grew up in Norilsk, a city beyond the Arctic Circle, in Siberia, and graduated from the Tomsk State University in 1977. She got her PhD in Physics and Mathematics at Leningrad State University in 1990, and the DSci in Physics and Mathematics at St. Petersburg State University in 2002. She currently teaches advanced courses within her faculty, and supervises BSc, MSc, and PhD theses. She has been a reviewer for several PhD and DSci theses, as well. She is the Principal Researcher and the head of a group with a number of grants from the Russian Fund for Basic Research, in federal programs, and in programs of the Education and Science Ministry of the Russian Federation. She has been awarded the Medal of the Federation of Astronautics of Russia with the name of the academician V. P. Makeev; she has twice received the medal "For Merits Before Tomsk State University;" and she had asteroid 17859 named Galinaryabova by the International Astronomical Union (IAU). Within the IAU, she has held several positions, such as a member of the organizing committees of Division F Commissions 22 and F1, "Meteors, Meteorites and Interplanetary Dust." She is a member of the International Meteor Organization (IMO) Council. She has been a referee for most international astronomical journals. She is currently the Editor-in-Chief of the Meteoroids book project under the auspices of the IAU.

Galina's research interests are mathematical modeling of meteoroid streams, interrelations in the asteroid-comet-meteoroid complex, and the dynamics of small bodies of the Solar System. She has published 63 scientific papers, mostly in English, and a textbook in Russian.

URSI Conference Calendar

URSI cannot be held responsible for any errors contained in this list of meetings

October 2016

RADIO 2016
IEEE Radio and Antenna Days of the Indian Ocean 2016
Réunion Island, 10-13 October 2016
Contact: radio2016@radiosociety.org
http://www.radiosociety.org/radio2016/

RFI 2016
Radio Frequency Interference 2016
Socorro, NM, USA, 17-20 October 2016
Contacts: Prof. F. Gronwald, TU HH (E), gronwald@tuhh.de; Dr. A.K. Mishra, U Capetown (F), amit.india@gmail.com; Dr. D. Levine , NASA (F), david.m.levine@nasa.gov; Dr. H. Rotkaehl, CBK Warsaw (H), hrot@cbk.waw.pl; Prof. W. Baan, ASTRON (J), baan@astron.nl
http://go.nrao.edu/rfi2016

ISAP 2016
2016 International Symposium on Antennas and Propagation
Okinawa, Japan, 24-28 October 2016
Contact: Prof. Toru Uno, Tokyo Univ. of Agriculture & Technology, Dept of Electrical and Electronic Engineering, 2-24-16 Nakamachi, Koganei 184-8588, Japan, Fax +81 42-388 7146, E-mail: uno@cc.tuat.ac.jp
http://isap2016.org/

PRE 8
8th International Workshop on Planetary, Solar and Heliospheric Radio Emissions
Seggauberg (near Graz), Austria, 25-27 October 2016
Contact: Prof. Georg Fischer, Space Research Institute, Austrian Academy of Sciences, E-mail: georg.fischer@oeaw.ac.at,
http://pre8.oeaw.ac.at/

November 2016

SCOSTEP/ISWI International School on Space Science
Sangli, India, 7-17 November 2016
Contact: Dr. Dadaso Jaypal Shetti, Department of Physics, Smt. Kasturbai Walchand College, Sangli, Maharashtra-416416, India, E-mail:- iswi2016@gmail.com, Fax: +91-233-2327128
http://www.iiap.res.in/meet/school_meet/index.php

January 2017

USNC-URSI NRSM 2017
USNC-URSI National Radio Science Meeting 2017
Boulder, CO, USA, 4-7 January 2017
Contact: Dr. Jean-Pierre DAMIANO, UNS, E-mail: ursi-france@mines-telecom.fr, http://ursi-france.telecom-paristech.fr/evenements/journees-scientifiques/2017/2017-en.html

February 2017

URSI-France 2017 Workshop dedicated to "Radio Science for Humanity"
Sophia Antipolis, France, 1-3 February 2017
Contact: Contact: Dr. David R. Jackson, Department of ECE, University of Houston, Houston, TX 77204-4005, USA, Fax: 713-743-4444, E-mail: djackson@uh.edu; Logistics: Christina Patarino, E-mail: christina.patarino@colorado.edu, Fax: 303-492-5959, https://nrsmboulder.org/

March 2017

URSI - RCRS 2017
3rd URSI Regional Conference on Radio Science 2017
Tirupati, Andhra Pradesh, India, 1-4 March 2017
Contact: Dr. T.V.Chandrasekhar Sarma, National Atmospheric Research Laboratory, Gadanki, India, E-mail: ursircrs2017@narl.gov.in, https://ursircrs2017.narl.gov.in

August 2017

URSI GASS 2017
XXXIInd URSI General Assembly and Scientific Symposium
Montreal, Canada, 19-26 August 2017
Contact: URSI Secretariat, Ghent University - INTEC, Technologiepark - Zwijnaarde 15, 9052 Gent, Belgium, E-mail info@ursi.org

Metamaterials 2017
The Eleventh International Congress on Advanced Electromagnetics Materials in Microwaves and Optics The Eleventh International Congress on Artificial Materials for Novel Wave Phenomena
Marseille, France, 28-31 August 2017
http://congress2017.metamorphose-vi.org
Contact: contact@metamorphose-vi.org

May 2018

AT-RASC 2018
Second URSI Atlantic Radio Science Conference
Gran Canaria, Spain, 28 May – 1 June 2018
Contact: Prof. Peter Van Daele, URSI Secretariat, Ghent University – INTEC, Technologiepark-Zwijnaarde 15, B-9052 Gent, Belgium, Fax: +32 9-264 4288, E-mail address: E-mail: peter.vandaele@intec.ugent.be
http://www.at-rasc.com

March 2019

C&RS "Smarter World"
18th Research Colloquium on Radio Science and Communications for a Smarter World
Dublin, Ireland, 8-9 March 2019
Contact: Dr. C. Brennan (Organising Cttee Chair)
http://www.ursi2016.org/content/meetings/mc/Ireland-2017-CRS Smarter World CFP.pdf

AP-RASC 2019
2019 URSI Asia-Pacific Radio Science Conference
New Delhi, India, 9-15 March 2019
Contact: Prof. Amitava Sen Gupta, E--mail: sengupto53@yahoo.com

May 2019

EMTS 2019
2019 URSI Commission B International Symposium on Electromagnetic Theory
San Diego, CA, USA, 27-31 May 2019
Contact: Prof. Sembiam R. Rengarajan, California State University, Northridge, CA, USA, Fax +1 818 677 7062, E-mail: srengarajan@csun.edu

Information for Authors

Content

The *Radio Science Bulletin* is published four times per year by the Radio Science Press on behalf of URSI, the International Union of Radio Science. The content of the *Bulletin* falls into three categories: peer-reviewed scientific papers, correspondence items (short technical notes, letters to the editor, reports on meetings, and reviews), and general and administrative information issued by the URSI Secretariat. Scientific papers may be invited (such as papers in the *Reviews of Radio Science* series, from the Commissions of URSI) or contributed. Papers may include original contributions, but should preferably also be of a sufficiently tutorial or review nature to be of interest to a wide range of radio scientists. The *Radio Science Bulletin* is indexed and abstracted by INSPEC.

Scientific papers are subjected to peer review. The content should be original and should not duplicate information or material that has been previously published (if use is made of previously published material, this must be identified to the Editor at the time of submission). Submission of a manuscript constitutes an implicit statement by the author(s) that it has not been submitted, accepted for publication, published, or copyrighted elsewhere, unless stated differently by the author(s) at time of submission. Accepted material will not be returned unless requested by the author(s) at time of submission.

Submissions

Material submitted for publication in the scientific section of the *Bulletin* should be addressed to the Editor, whereas administrative material is handled directly with the Secretariat. Submission in electronic format according to the instructions below is preferred. There are typically no page charges for contributions following the guidelines. No free reprints are provided.

Style and Format

There are no set limits on the length of papers, but they typically range from three to 15 published pages including figures. The official languages of URSI are French and English: contributions in either language are acceptable. No specific style for the manuscript is required as the final layout of the material is done by the URSI Secretariat. Manuscripts should generally be prepared in one column for printing on one side of the paper, with as little use of automatic formatting features of word processors as possible. A complete style guide for the *Reviews of Radio Science* can be downloaded from http://www.ips.gov.au/IPSHosted/NCRS/reviews/. The style instructions in this can be followed for all other *Bulletin* contributions, as well. The name, affiliation, address, telephone and fax numbers, and e-mail address for all authors must be included with All papers accepted for publication are subject to editing to provide uniformity of style and clarity of language. The publication schedule does not usually permit providing galleys to the author.

Figure captions should be on a separate page in proper style; see the above guide or any issue for examples. All lettering on figures must be of sufficient size to be at least 9 pt in size after reduction to column width. Each illustration should be identified on the back or at the bottom of the sheet with the figure number and name of author(s). If possible, the figures should also be provided in electronic format. TIF is preferred, although other formats are possible as well: please contact the Editor. Electronic versions of figures *must* be of sufficient resolution to permit good quality in print. As a rough guideline, when sized to column width, line art should have a minimum resolution of 300 dpi; color photographs should have a minimum resolution of 150 dpi with a color depth of 24 bits. 72 dpi images intended for the Web are generally *not* acceptable. Contact the Editor for further information.

Electronic Submission

A version of Microsoft *Word* is the preferred format for submissions. Submissions in versions of $\mathrm{T_EX}$ can be accepted in some circumstances: please contact the Editor before submitting. *A paper copy of all electronic submissions must be mailed to the Editor, including originals of all figures.* Please do *not* include figures in the same file as the text of a contribution. Electronic files can be send to the Editor in three ways: (1) By sending a floppy diskette or CD-R; (2) By attachment to an e-mail message to the Editor (the maximum size for attachments *after* MIME encoding is about 7 MB); (3) By e-mailing the Editor instructions for downloading the material from an ftp site.

Review Process

The review process usually requires about three months. Authors may be asked to modify the manuscript if it is not accepted in its original form. The elapsed time between receipt of a manuscript and publication is usually less than twelve months.

Copyright

Submission of a contribution to the *Radio Science Bulletin* will be interpreted as assignment and release of copyright and any and all other rights to the Radio Science Press, acting as agent and trustee for URSI. Submission for publication implicitly indicates the author(s) agreement with such assignment, and certification that publication will not violate any other copyrights or other rights associated with the submitted material.

Application for an URSI Radioscientist

APPLICATION FOR URSI RADIOSCIENTIST

I have not attended the last URSI General Assembly & Scientific Symposium, and wish to remain/become an URSI Radioscientist in the 2014-2017 triennium. This application includes a subscription to *The Radio Science Bulletin* and inclusion in the URSI mailing lists.

(Please type or print in BLOCK LETTERS)

Name : Prof./Dr./Mr./Mrs./Ms. ______________________________
Family Name First Name Middle Initials

Present job title: ______________________________

Years of professional experience: ____________

Professional affiliation: ______________________________

I request that all information be sent to my ☐ home ☐ business address, i.e.:

Company name: ______________________________

Department: ______________________________

Street address: ______________________________

City and postal/zip code: ______________________________

Province/State: ____________________ Country: ______________

Tel: ________________ ext. ______ Fax: ______________

E-mail: ______________________________

Areas of interest *(Please tick)*

- ☐ A Electromagnetic Metrology
- ☐ B Fields and Waves
- ☐ C Radio-Communication Systems & Signal Processing
- ☐ D Electronics and Photonics
- ☐ E Electromagnetic Environment & Interference
- ☐ F Wave Propagation & Remote Sensing
- ☐ G Ionospheric Radio and Propagation
- ☐ H Waves in Plasmas
- ☐ J Radio Astronomy
- ☐ K Electromagnetics in Biology & Medicine

☐	By signing up, you agree to be included into the URSI mailing list. You can unsubscribe at any time.
☐	I agree that my contact details will be used by URSI only and will never be transferred to other parties.

Please return this signed form to :

The URSI Secretariat
Ghent University - INTEC
Technologiepark - Zwijnaarde
B-9052 GHENT, BELGIUM
E-mail: info@ursi.org